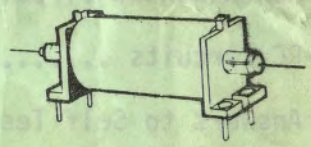
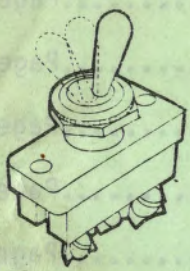
WIRELESS INSTITUTE OF AUSTRALIA

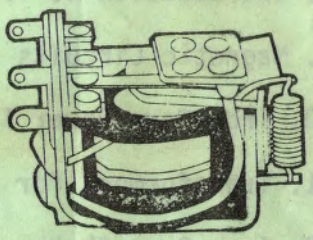
Youth Radio Clubs Scheme

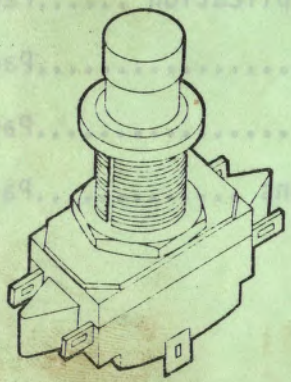
ELEMENTARY STAGE TWO

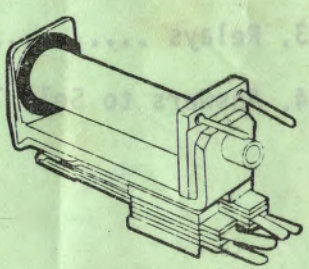
BOOK THREE











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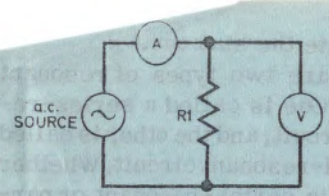
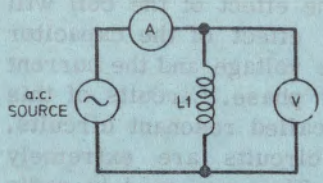
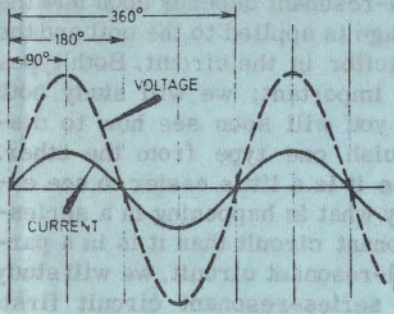
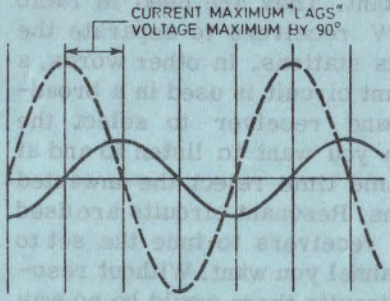








RESISTOR—CAPACITOR—INDUCTOR COMBINATION

In the preceding lessons you have studied resistors, coils and capacitors. Other than tubes and transistors, these are the three most important parts you will run into in electronic equipment. In your studies of these parts you have been primarily concerned with the part itself, with its characteristics and briefly with how it is made. In electronic equipment these parts are seldom used alone; in most cases two or more of these parts will be used together. For example, in coupling circuits, you will often use combinations of resistors and capacitors to feed the signal from one audio stage to a second audio stage. Circuits of this type are referred to as RC coupling circuits.

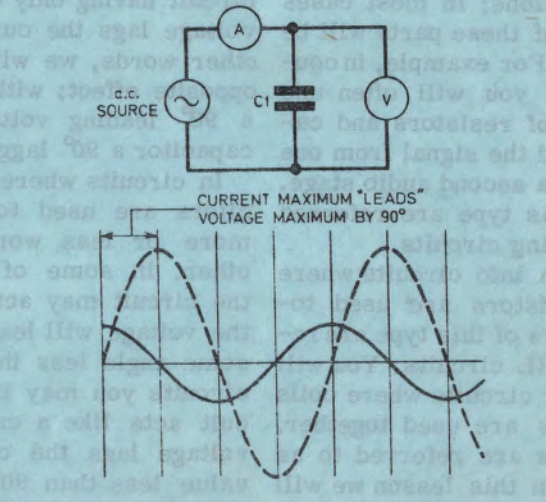
You will run into circuits where coils and resistors are used together. Circuits of this type are referred to as RL circuits. You will also encounter circuits where coils and capacitors are used together. These circuits are referred to as LC circuits. In this lesson we will study all three types of circuits but will spend most of the time on LC circuits because these are perhaps the most important of the three.

From your studies of the coil and the capacitor you might remember that in many ways one is the opposite of the other. For example, in a circuit having only inductance, you will recall that the voltage leads the current by 90°. On the other hand, in a circuit having only capacitance, the voltage lags the current by 90°. In other words, we will get the exact opposite effect; with a coil we have a 90° leading voltage and with a capacitor a 90° lagging voltage.

In circuits where coils and capacitors are used together the two more or less work against each other. In some of these circuits, the circuit may act like a coil and the voltage will lead the current by some angle less than 90°. In other circuits you may find that the circuit acts like a capacitor and the voltage lags the current by some value less than 90°. In still other

circuits the effect of the coil will cancel the effect of the capacitor so that the voltage and the current will be in phase. Circuits of this type are called resonant circuits. Resonant circuits are extremely important. They are used in radio and TV receivers to separate the various stations. In other words, a resonant circuit is used in a broadcast-band receiver to select the station you want to listen to and at the same time reject the unwanted stations. Resonant circuits are used in TV receivers to tune the set to the channel you want. Without resonant circuits there would be no way to separate the stations.

There are two types of resonant circuits. One is called a series-resonant circuit, and the other is called a parallel-resonant circuit. Whether a circuit is series-resonant or parallel-resonant depends upon how the voltage is applied to the coil and the capacitor in the circuit. Both types are important; we will study both and you will soon see how to distinguish one type from the other. Since it is a little easier to see exactly what is happening in a series-resonant circuit than it is in a parallel-resonant circuit, we will study the series-resonant circuit first.



Series-Resonant Circuits

A resonant circuit is a circuit in which the inductive reactance of the coil is equal to the capacitive reactance of the capacitor. When the voltage is applied to the coil and the capacitor in series we call the circuit a series-resonant circuit. To help you get a clear understanding of what a series-resonant circuit is, let us start with a simple series circuit and review some of the things you already know.

A SERIES CIRCUIT

Let's begin with the circuit shown in Fig. 1, consisting of a 500-cycle ac generator that is generating a voltage of 120 volts. Across this generator we will connect a variable resistor, which is set so that it has a resistance of 120 ohms. If we have a voltmeter connected across the resistor, the voltage reading will be close to 120 volts. This is true because the resistor is connected directly across the generator, and the voltage being supplied by the generator is 120 volts. An ammeter connected in series with the resistor will indicate that the current flowing in the circuit is 1 ampere. Actually, we do not need the ammeter to tell us this, because we know that we can determine the current by dividing the voltage by the resistance. Remember this formula for Ohm's Law:

$$I = \frac{E}{R}$$

Therefore

$$I = \frac{120}{120} = 1 \text{ amp}$$

In this simple circuit we know that the current will be in phase with the voltage, because the only element connected in the circuit is resistance. This means that the voltage across the resistor will reach its peak at the same time that the current flowing in the circuit is at a maximum.

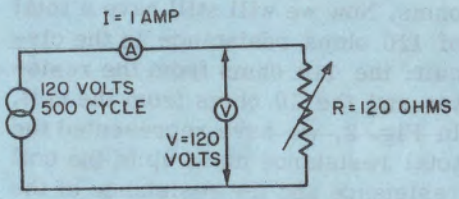


Fig. 1. A simple series circuit.

Remember that the voltmeter and the ammeter are measuring the effective value (or the rms value) of the ac voltage and current and that during part of the cycle, the generator voltage actually exceeds 120 volts. You will recall that the peak voltage of an ac sine wave will be 1.41 times the effective voltage. Therefore, even though the meter is reading 120 volts, the voltage will be greater than this value during part of the cycle and less than this value during the other part of the cycle. The voltage will actually be zero twice each cycle. Likewise, the current is the effective current and its actual value will be greater than 1 amp twice each cycle and less than 1 amp the remainder of the time. The current will reach a peak value of 1.41 amps twice each cycle and will actually drop to 0 twice each cycle.

AN RL CIRCUIT

Now let us see what happens when we modify the simple circuit of Fig. 1 by adding a 100-mh (millihenry) coil in series with the resistor as shown in Fig. 2. In Fig. 1 we showed the resistor as a variable resistor. We did this deliberately because you know that any coil will have some resistance. If the 100-millihenry coil has a resistance of 10 ohms, we can adjust the variable resistor so that its resistance is only 110 ohms. Now we will still have a total of 120 ohms resistance in the circuit: the 110 ohms from the resistor and the 10 ohms from the coil. In Fig. 2, we have represented the total resistance made up of the coil resistance and the resistance of the variable resistor as only one 120-ohm resistor. Notice that in Fig. 2 we have the ammeter in series with both the coil and resistor and have added a second voltmeter across the coil. But look at the readings on the meters! The ammeter shows that the current flowing is .35 amp. The voltmeters show that the voltage across the resistor is 43 volts, and the voltage across the coil is 112 volts. You have already seen this type of circuit, and probably know why we have obtained these readings, but let's go through this again to be sure you understand why such

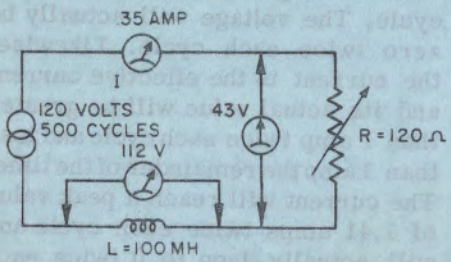


Fig. 2. A simple RL series circuit.

voltage readings are obtained. You may at first think this looks complicated, but actually it is not nearly as difficult as it might appear.

First, we have a series circuit. We know that the total opposition to the current flowing in the circuit will be the impedance of the circuit, which in turn is made up of the 120-ohm resistance plus the inductive reactance of the coil. We can find the inductive reactance of the coil from the formula:

$$X_L = 6.28 \times F \times L$$

Since 100-mh is .1 henry, L = .1 and F = 500 cycles, we have:

$$X_L = 6.28 \times 500 \times .1$$

$$= 314 \text{ ohms}$$

As you might expect, it is extremely difficult to make a coil with an inductance of exactly 100 millihenrys. Furthermore, we are not interested in exact calculations in most electronic circuits. To simplify things, we are going to call the inductive reactance of the coil 315 ohms. The impedance of the circuit is therefore equal to 120 ohms plus the reactance of 315 ohms. To show this by means of symbols, electronics men write this as

$$Z = 120 + j315$$

The letter j is used to indicate that 315 ohms is a reactive component which cannot be added directly to 120 ohms to get the total impedance of the circuit. If we simply wrote the impedance as 120 + 315, it would be very easy to forget that 120 was resistance and 315 was reactance and simply add the two and get 435 ohms, which of course, is incorrect.

The value of Z can be determined either by vectors as shown in Fig. 3 or from the formula

$$Z = \sqrt{R^2 + X^2}$$

In this case R is 120 ohms, and X is the inductive reactance, which is 315 ohms. So we have:

$$Z = \sqrt{120^2 + 315^2}$$

Remember that the small 2 to the right of 120 and 315 means that the number is to be squared, and that 120 squared is equal to 120 times 120. If you want to go through the arithmetic, the actual operations of squaring these numbers are as follows

120	315
× 120	× 315
2400	1575
120	315
14400	945
	99225

Now that we have the value of 120 and 315 squared, we have

$$Z = \sqrt{14{,}400 + 99{,}225}$$

and by adding these we will get

$$\begin{array}{r} 14400 \\ +\ 99225 \\ \hline 113625 \end{array}$$

Therefore $Z = \sqrt{113{,}625}$

To get the value of Z we have to take the square root of 113,625. This is done by first writing the number down and then marking it off in groups of two numbers working from the decimal point to the left. The steps in getting this square root are as follows:

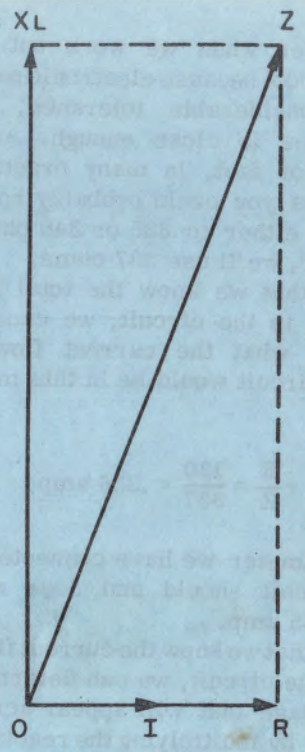


Fig. 3. Vector addition of R and X_L using a scale of 100 ohms = 1 inch, when R = 120 ohms, and X_L = 315 ohms. R is drawn 1.2 inches long, and X_L is drawn slightly less than 3.2 inches long. The impedance vector Z is then found by completing the rectangle and drawing Z from zero to the junction of the dotted lines. Z will measure between 3.25 and 3.5 inches, giving a Z of about 340 ohms.

$$\begin{array}{r|l} \sqrt{11'\,36'\,25'} & 337 \\ 9 & \\ \hline 63 \mid\ 236 & \\ 189 & \\ \hline 667 \mid\ 4725 & \\ 4669 & \\ \hline 56 & \end{array}$$

Therefore, the impedance of the circuit is 337 ohms. We need not be concerned if there is a slight

remainder when we work out the square root because electronic parts have considerable tolerance, and 337 ohms is close enough. As a matter of fact, in many practical problems you could probably round this off either to 335 or 340 ohms. However, we'll use 337 ohms.

Now that we know the total impedance in the circuit, we can determine what the current flowing in the circuit would be in this manner:

$$I = \frac{E}{Z} = \frac{120}{337} = .356 \text{ amp}$$

The ammeter we have connected in the circuit should and does read about .35 amp.

Now that we know the current flowing in the circuit, we can determine the voltage that will appear across the coil by multiplying the reactance of the coil by the current flowing in the circuit. In other words:

$$E_L = I \times X_L$$

Multiplying .356 × 315 we get 112.14 volts. We do not have to be concerned with such accuracy as this; we will simply call the voltage 112 volts. As a matter of fact this is the voltage indicated by the voltmeter connected across the coil; you cannot get a more accurate reading. Similarly, the voltage across the resistor is

$$E_R = I \times R$$

which is equal to .356 × 120, or 42.72 volts. We will round this off to 43 volts, which is what the meter will indicate.

Each of the steps that we have shown in the preceding example is important. It is not particularly necessary that you sit down and follow through the multiplication and division unless you want to do so. If you expect to go into radio and TV servicing you will have no occasion to do this type of work, but if you intend to go into industry as an electronics technician, you should be sure you understand the various steps in this circuit explanation.

Whether you go through the mathematics or not, there are several important points you should see. The current flowing in the circuit is limited by the impedance of the circuit. The impedance, as you know, is the total opposition to current flow in the circuit. The voltage that will appear across each part in the circuit will depend upon the resistance or reactance of that part and upon the current flowing in the circuit. Also, you should remember that in this example, although it may appear that the sum of the voltage across the coil plus the voltage across the resistance is greater than the source voltage, the meters are measuring the effective value of the voltage and that these voltages are not in phase. These voltages are ac voltages and hence continually changing, but the voltage across the resistor plus the voltage across the coil at any given instant is exactly equal to the source voltage at that instant.

THE RC CIRCUIT

Now, let's remove the 100-mh coil from the circuit and put a 1-mfd capacitor in its place. We will readjust the variable resistance so that the total resistance of the circuit is 120 ohms. We will then have the circuit shown in Fig. 4. Notice that

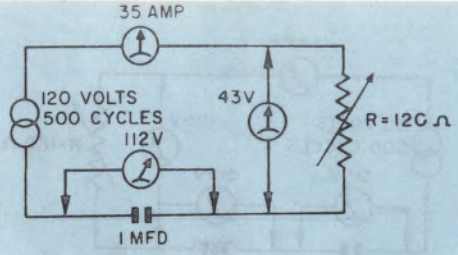


Fig. 4. A simple RC series circuit.

the voltage across the resistance is the same as in Fig. 2, and also notice that the voltage across the capacitor in Fig. 4 is the same as the voltage across the coil in Fig. 2.

We can verify all the meter readings shown in Fig. 4 as we did for the circuit shown in Fig. 2. To do this, we start by finding the reactance of the 1-mfd capacitor at 500 cycles from the formula:

$$X_C = \frac{1}{6.28 \times F \times C}$$

The capacitive reactance of the capacitor turns out to be 318 ohms. We will round this off to 315 ohms, because it is unlikely that the capacitor will have a capacity of exactly 1 microfarad. You do not have to go through the solution of this formula unless you want to, but for the benefit of those who want to work it out step by step we'll go through it.

First, remember that in the formula the frequency must be in cycles and the capacity must be in farads. Therefore, F = 500 cycles and C = 1 mfd = .000001 farad. Substituting these values in the formula we have

$$X_C = \frac{1}{6.28 \times 500 \times .000001}$$

Now we can start by multiplying 6.28 × 500 and we will get

$$\begin{array}{r} 6.28 \\ \times\ 500 \\ \hline 3140.00 \end{array}$$

Next, multiplying 3140 by .000001, we will get

$$\begin{array}{r} 3140 \\ \times\ .000001 \\ \hline .003140 \end{array}$$

The next step in our problem is to divide 1 by .003140. To perform the division we must get rid of the decimal point; to do this we move the decimal point six places in the divisor and six places in the dividend so that our problem becomes 1000000 divided by 3140:

$$.003140 \overline{)\,1.000000}$$

$$\begin{array}{r} 318 \\ 3140 \overline{)\,1000000} \\ 9420 \\ \hline 5800 \\ 3140 \\ \hline 26600 \\ 25120 \\ \hline 1480 \end{array}$$

As we mentioned we will round off the value of the capacitive reactance to 315 ohms. The difference is so small that whether it is 315 or 318 you won't be able to detect any difference in the meter readings in Fig. 4. Using 315 ohms as the capacitive reactance makes the total impedance of the circuit

$$Z = 120 - j315$$

Notice that in this case we have used -j to indicate that 315 ohms is a capacitive reactance. Actually, whether the sign is minus or plus will make no difference in deter-

mining the value of the impedance. We still use the formula:

$$Z = \sqrt{R^2 + X^2}$$

In this case, X is the capacitive reactance. Even though it is shown as -j315, it will still be + when squared, because any number squared is positive. Our formula is therefore the same as before:

$$Z = \sqrt{120^2 + 315^2}$$

The impedance works out again to be 337 ohms. The current flowing in the circuit can then be found by dividing the voltage by the impedance; this is 120 ÷ 337, or .356 amp. We can find the voltage across the resistor by multiplying the current, .356 amp, by the resistance, 120 ohms. Thus, .356 × 120 = 43 volts. Similarly, the voltage across the capacitor is .356 × 315, or 112 volts.

It is worthwhile to notice that since the circuit shown in Fig. 2 contains inductance and resistance the current will be lagging the voltage. In the circuit shown in Fig. 4 the current will be leading the voltage since we have capacitance and resistance. Nevertheless, the total impedance is the same in the two circuits; therefore, the currents flowing in the circuits are equal, which accounts for the equal voltage appearing across the resistors in each circuit.

Now let us see what happens when we go one step further and put the 100-mh coil in series with the 120-ohm resistor and the 1-mfd capacitor.

THE RESONANT CIRCUIT

In the circuit shown in Fig. 5, we have 120-ohm resistance in series

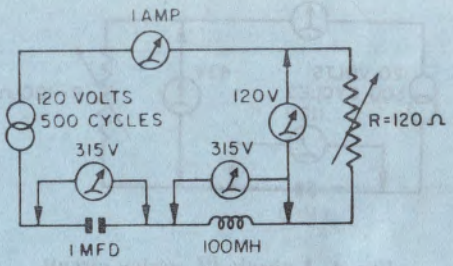


Fig. 5. A series-resonant circuit.

with the 100-mh coil and the 1-mfd capacitor, and the series combination connected across the 120-volt, 500-cycle generator. The inductive reactance of the coil and the capacitive reactance of the capacitor will each be approximately 315 ohms as before, because the frequency in the circuit has not changed. Therefore, the total impedance in the circuit will be

$$Z = 120 + j315 - j315$$

We have already pointed out that capacitive reactance is essentially the opposite of inductive reactance. We have indicated this by using +j to represent inductive reactance and -j to represent capacitive reactance.

In the expression for the impedance of the circuit you see +j315 and -j315, and, as you might expect, these two cancel so that the total impedance of the circuit is equal to the resistance of the resistor alone, or 120 ohms.

Now let's see what happens to the voltages and current throughout the circuit. First, look at the current flowing; it is 1 amp. It is higher than it was in Fig. 2 and Fig. 4. The reason for this is that the current is equal to

$$I = \frac{E}{Z}$$

Z in Fig. 5 is 120 + j315 - j315, or 120 ohms. Therefore I = 120 ÷ 120, or 1 amp.

The voltage across the coil is 315 volts. This is equal to the current times the inductive reactance: 1 amp × 315 ohms = 315 volts. Similarly, the voltage across the capacitor will be equal to 315 volts. The voltage across the resistor is 120 volts. Notice what we now have across the capacitator and across the inductance: a voltage several times the source voltage. This is referred to as a "resonant voltage step-up." In other words, the voltage across the coil and the voltage across the capacitor in a series-resonant circuit may be several times the source voltage.

In the preceding example we saw that the impedance of the circuit at resonance is equal to the resistance in the circuit. Now you might wonder what happens when you change the resistance in the circuit. If you reduce the value of the resistance in the circuit, you will reduce the impedance. If we cut the resistance in half so that the total resistance in the circuit is only 60 ohms, the current flowing in the circuit will be doubled. We will then have the situation shown in Fig. 6. Here the voltage drop across the capacitor is equal to 2 amps × 315 ohms, or 630 volts. Similarly, the voltage appearing across the coil will be 630 volts and the voltage across the resistor will be 2 amps × 60 ohms, which is equal to 120 volts as before. Now we have an even greater resonant voltage step-up than we had previously. Reducing the resistance still further will result in an even greater voltage appearing across the coil and across the capacitor.

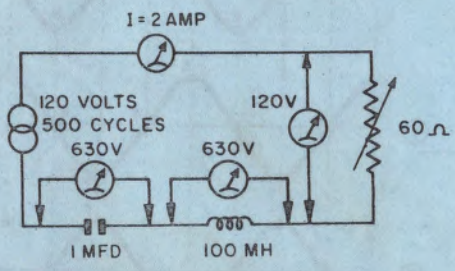


Fig. 6. Reducing the resistance in the series-resonant circuit results in a greater current flow and a higher resonant voltage step-up.

In a practical resonant circuit, we will have only a capacitor and a coil in series. However, there will always be resistance in the circuit because the coil is made by winding turns of copper wire on a coil form, and the copper wire has resistance. However, the lower that resistance can be made, the lower the impedance of the circuit and the greater the resonant voltage step-up will be.

This can be expressed in another way. The Q of a coil is equal to the inductive reactance divided by the resistance of the coil. In other words:

$$Q = \frac{X_L}{R}$$

In a coil where the resistance is low, the value of Q will be high. Since the lower the resistance we have, the greater the resonant step-up voltage will be, we say that there will be more resonant voltage step-up in a high-Q circuit than in a low-Q circuit.

Series-Resonant Facts.

Before going ahead with our study of series-resonant circuits, we should review several of the things that we have already discussed.

First, in a series-resonant circuit at resonance the inductive reactance is exactly equal to and can-

cels the capacitive reactance in the circuit so that the impedance of the circuit is equal to the resistance in the circuit. The impedance in the circuit will therefore be low, and the current flowing in the circuit will be high. Second, there is a resonant voltage step-up in a series-resonant circuit.

Remember these two facts -- they are important: in a series-resonant circuit you will have low impedance and high current and the voltage appearing across either the capacitor or inductance may be several times the source voltage.

Resonance occurs when the inductive reactance of the coil exactly equals the capacitive reactance of the capacitor. In other words,

$$X_L = X_C$$

$$6.28 \times F \times L = \frac{1}{6.28 \times F \times C}$$

and from this we can get:

$$F = \frac{1}{6.28 \times \sqrt{L \times C}}$$

This is the frequency at which a coil and a capacitor will be resonant.

VOLTAGE AND CURRENT WAVEFORMS IN THE SERIES-RESONANT CIRCUIT

In any series circuit, the current is always the same in all parts of the circuit. This is true whether it is a resonant circuit or a simple series circuit consisting of a number of resistors. Therefore, in a circuit such as the one shown in Fig. 7A the current flowing through the generator will be equal to the current flowing through the coil at all times, whether the circuit is resonant or not. This current is also equal to the current flowing through the resistor and to the current flowing through the capacitor.

If the circuit shown in Fig. 7A is a resonant circuit, we can make use of the fact that the current is the same at all times in all parts of the circuit to get a better idea of what is happening. We can do this by studying the voltage and current waveforms throughout the circuit. For example, we have shown two cycles and have identified a number of points on these cycles by numbers in Fig. 7B. This waveform represents the entire current flowing in the series-resonant circuit.

Look at the current waveform at point 1 and notice that the current begins swinging in a positive direction. Let's assume that at this instant the voltage at terminal a of

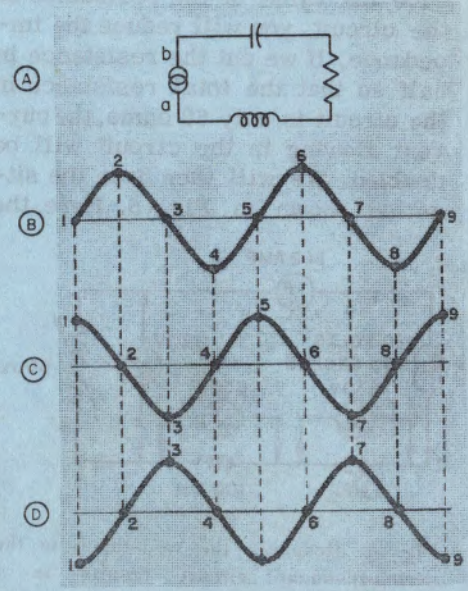


Fig. 7. Series-resonant circuit waveforms.

the generator begins to swing in a negative direction so that current starts flowing at terminal a through the coil and around the circuit back to terminal b of the generator. As the waveform increases in amplitude from point 1 to point 2, current increases in the circuit going from 0 at point 1 to its maximum value at point 2.

Although we have started the waveform shown in 7B at point 1, we are actually representing what happens in a series-resonant circuit in which the current has been flowing for some time. In other words, the circuit has been connected to the generator (which is producing the current) and we simply started to analyze what is happening in the circuit at the given instant designated at point 1 on the curve B. At this instant the current flowing in the circuit has just reached 0 and has begun to increase towards point 2 as electrons move from terminal a of the generator around the circuit towards terminal b of the generator.

Fig. 7B is a sine wave. A sine wave changes value at a maximum rate at the instant it is going through 0. In other words, at point 1 the rate at which the value of the current (represented by the sine wave) changes is at a maximum. As the actual current amplitude increases towards point 2, the rate of change decreases until for an instant at point 2 there is no change in current. The current has reached its maximum value, it remains constant for just an instant at point 2, and then begins to decrease. The rate at which it decreases increases until it is changing at its maximum rate when it reaches point 3. For just an instant the current drops to 0 at point 3. Thus, the current goes through a complete change - the instant before it reaches point 3 it is flowing in one direction, it drops to 0 exactly at point 3 and then an instant later it is flowing in the opposite direction.

Now let us consider what effect this changing current has on the voltage across the coil. Remember that the self-induced voltage in a coil depends upon the rate at which the current flowing through the coil changes. Therefore, at point 1, since the current is changing at its maximum rate, the self-induced voltage induced in the coil will be at maximum. As the current increases in amplitude towards point 2, the rate at which it is changing decreases so the voltage induced in the coil decreases. At point 2, where the current is not changing at all, the voltage induced in the coil will be 0. This is shown by the portion of curve C between points 1 and 2. Now, as the current begins to decrease from point 2 to point 3 the rate at which the current is changing increases. Since the current is decreasing, a voltage is induced in the coil which tends to oppose the direction in which the current is changing. Therefore, as the current goes from point 2 to point 3 (as shown in the curve at B), the voltage across the coil will increase from 0 at point 2 to its maximum value at point 3 (as shown in the curve at C).

Notice that the voltage across the coil is leading the current by 90°. If you remember your earlier studies, this is exactly what you might expect. As the current goes through the remainder of its cycle (as shown from point 3 on over to point 9), the voltage across the coil will at all times be 90° ahead of this current.

Now let us consider what must be happening across the resistor and capacitor in the circuit. At point 1 on curve B the actual value of the current flowing is 0. Therefore, the voltage across the resistor must be 0 because it will be in phase with the current. We have not drawn a wave shape to represent the voltage across the resistor because it will be in phase with the current waveform shown at B at all times.

Since the voltage across the generator is 0 at point 1 and the voltage across the resistor is also 0 at point 1, we immediately see that the voltage across the capacitor must be exactly equal to and opposite to the voltage across the coil. We know this must be true because in any closed circuit of this type the algebraic sum of the voltage drops around the circuit must be equal to 0. Indeed, if the circuit has been in operation the capacitor would be charged with a polarity equal to and opposite to the voltage across the coil at the instant that the current was at 0, as at point 1. As the current increases from point 1 to point 2, electrons will flow into the capacitor to reduce the charge until at point 2 the charge on the capacitor will be exactly equal to 0. As current continues to flow in the same direction (as shown from point 2 to point 3 on curve B) electrons will continue to flow into one plate of the capacitor and charge it (as shown between points 2 and 3 on curve D).

Notice what has happened. At each instant, the voltage across the capacitor is equal to and opposite to the voltage across the coil. Also notice that the voltage across the capacitor is lagging the current flowing in the circuit by 90°. This is as we should expect; when you studied capacitors in earlier lessons, you learned that the voltage lags the current in a capacitor by 90°.

The curves in Fig. 7 show what happens in a series-resonant circuit and why the voltages around the circuit (if they are measured separately, then added together) will be equal to a value greater than the source voltage. If you measure the capacitor voltage you'll be measuring the rms value of the waveform shown at D. If you measure the coil voltage you will be measuring the rms value of the curve shown at C. While these voltages do exist across the components, they are always 180° out of phase and therefore as far as the total voltage across the two is concerned they cancel each other.

In a series-resonant circuit that has a pure inductance and a pure capacitance in series with a resistor, the voltage across the inductance is exactly cancelled by the voltage across the capacitance. In this case, the applied voltage is developed across the resistor. However, pure inductors and capacitors do not exist. All coils have some resistance and all capacitors have some leakage. Therefore, the voltages across the coil and capacitor do not exactly cancel. Thus, a small voltage can be measured across the coil-capacitor combination.

Before going on to the next section of the lesson it would be worthwhile to study carefully the waveforms shown in Fig. 7 to be sure you understand what is happening. It might make it easier for you if you can redraw the circuit and place a resistor next to the generator instead of between the coil and the capacitor. Actually, insofar as the current flow in the circuit and the voltage across the individual parts in the circuit

are concerned, it makes no difference where the parts are placed. However, to see how the voltages across the coil and capacitor are cancelling, it might be easier to see this if you move the resistor so that it is not between the two.

VARYING L, C, F, AND R

When the inductive reactance in a series circuit is equal to the capacitive reactance, the circuit is at resonance, the two cancel each other, and we will have a low-impedance circuit in which we will get a high current flow. Let us see what happens if we use other values of C and L and if we vary the frequency of the voltage applied to the circuit. Let's start by seeing what will happen when we vary the value of the capacitor.

Varying C.

We can vary the value of C by inserting capacitors of different sizes in the circuit in place of the 1-mfd capacitor, while leaving the source frequency at 500 cycles and the coil inductance at 100 millihenrys. The current in the circuit will vary as shown in Fig. 8. Notice that we have the highest current flowing exactly at resonance. As the capacity is reduced, the current drops off rather sharply. It is important for you to realize that as the capacity is made smaller than it should be for resonance, the capacitive reactance in the circuit increases so that it is greater than the inductive reactance. Therefore, the inductive reactance does not completely cancel out all the capacitive reactance in the circuit, and the resonant circuit begins to act like a circuit having only capacity. In other words, the current flowing in the circuit will lead the voltage.

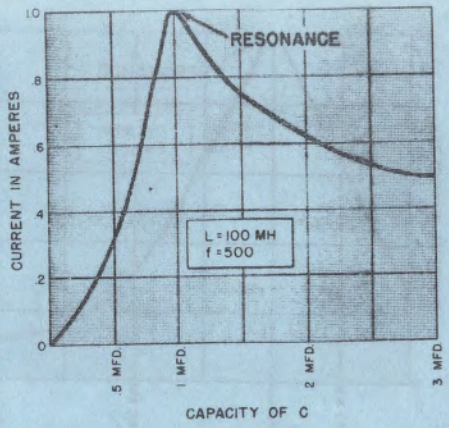


Fig. 8. How current varies in a series-resonant circuit when L is 100 mh, F is 500 cycles, and C is varied from 0 to 3 mfd.

As the capacity is increased above 1-mfd, the capacitive reactance decreases so that the inductive reactance in the circuit is greater than the capacitive reactance. Therefore, the inductive reactance cancels out all of the capacitive reactance and there is still some inductive reactance left over. The circuit begins to act like a circuit having only inductance in it and the current will lag the voltage.

In either case, when the capacity is too small or too high for resonance, the impedance of the circuit is greater than it is at resonance; this accounts for the reduction in current flow in the circuit.

Varying L.

If the inductance in the circuit is varied instead of the capacity, the current will vary as shown in Fig. 9. Here, when the size of the inductor or coil is reduced, the inductive reactance is decreased, and it will not completely cancel out the capacitive reactance in the circuit. The circuit will act like a capacitor, and the current will lead the voltage.

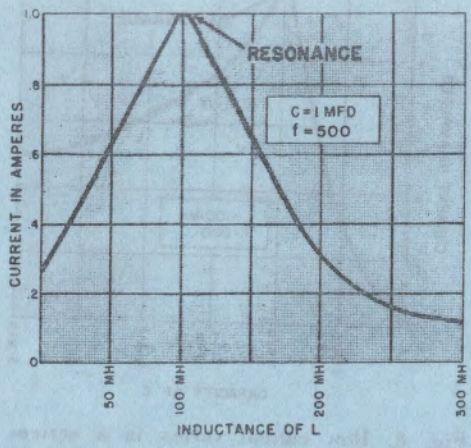


Fig. 9. How current varies in a series-resonant circuit when C = 1 mfd, F = 500 cycles, and L is varied from 0 to 300 mh.

When the inductance is made greater than 100-mh, then the inductive reactance is greater than the capacitive reactance and the circuit will act as an inductance. This means that the current will lag the voltage. Again, the current will be lower than at resonance when the inductance is made either too large or too small because the impedance in the circuit increases. Lowest impedance is obtained in a series-resonant circuit at resonance, when the inductive reactance cancels the capacitive reactance. Current will always be at maximum at this point.

Varying Both L and C.

The combination of a 100-mh coil and a 1-mfd capacitor is not the only combination that will give resonance at 500 cycles. If we double the inductance of the coil by using a 200-mh coil in the circuit, the inductive reactance of the coil will be doubled. It will be twice 315 ohms, or 630 ohms. If we reduce the size of the capacitor from 1-mfd to .5-mfd, we will also double the reactance of the capacitor so that its reactance will now be 630 ohms at 500 cycles. This means that with a 200-mh coil and a .5-mfd capacity, we will again have a situation where the inductive reactance will be equal to the capacitive reactance; therefore, these components will be resonant at 500 cycles.

You can see that many values of coil and capacitor may be used to obtain resonance at 500 cycles. Once we select a coil, it will have a certain inductive reactance at a frequency of 500 cycles. All we need is to obtain a capacitor that will have a capacitive reactance equal to the inductive reactance of the coil at this frequency, and we will have a resonant circuit at 500 cycles.

Varying F.

If we go back to the 100-mh coil and the 1-mfd capacitor and then vary the frequency of the voltage applied to this combination, we will obtain a curve like the one shown in Fig. 10. Notice that in this case we have maximum current flow at resonance, because at resonance the impedance of the circuit is lowest. When the frequency applied to the coil and capacitor combination is less than 500 cycles, the capacitive reactance of the capacitor is greater than the inductive reactance of the coil, so the combination acts like a capacitor and the current will lead the voltage.

When the frequency applied to the combination is above 500 cycles, then the inductive reactance of the coil is greater than the capacitive reactance of the capacitor, and the circuit will act like a coil. In either case, the impedance of the circuit will be minimal at resonance and higher either above or below the resonant frequency. The fact that the

impedance reaches its minimum at the resonant frequency of 500 cycles is the reason the current is at maximum.

Varying R.

Under certain circumstances, the total resistance in the circuit may be varied. As the resistance in the circuit is changed, the Q of the circuit changes and the current that will flow in this circuit changes. In Fig. 11, we have shown three resonance curves. The curve marked A is the one we had in Fig. 10 with a 100-mh coil, a 1-mfd capacitor, and a series resistance of 120 ohms. In the curve marked B, the inductance and capacity are the same, but the series resistance is 100 ohms.

Changing the resistance has an important effect on the shape of a resonant curve, as shown in Fig. 11.

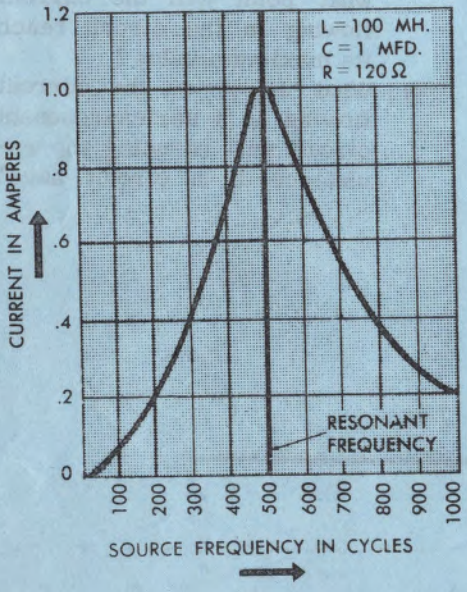


Fig. 10. How current varies in a series-resonant circuit when C = 1 mfd, L = 100 mh, R = 120 ohms, and F is varied from 0 to 1000 cycles.

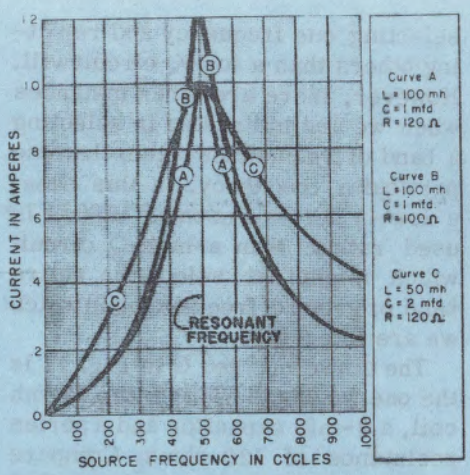


Fig. 11. How the current varies in a series-resonant circuit when F is varied, and (A) C = 1 mfd, L = 100 mh, and R = 120 ohms; (B) C = 1 mfd, L = 100 mh, and R = 100 ohms; (C) C = 2 mfd, L = 50 mh, and R = 120 ohms. In each case the product of L and C is the same, and resonance occurs at 500 cycles.

With a high-Q circuit, which is obtained when the resistance of the circuit is low, we have a very sharp curve. This means that we will get a much higher current flow at the resonant frequency of the circuit than we will get at a frequency either slightly above or slightly below the resonant frequency. However, with a low-Q circuit, we have a broad curve. This means that we can vary the frequency quite a bit either above or below the resonant frequency without causing a very great change in the current that will flow in the circuit.

The effect of resistance on a series-resonant circuit is important. Sometimes a series-resonant circuit may be used to select one frequency and reject all others. Obviously, if we have a high-Q circuit it will do a much better job of

selecting one frequency and rejecting others than a low-Q circuit will. However, there are other instances when we are interested in selecting a band of frequencies rather than one particular frequency. In this case, a low-Q series-resonant circuit is used rather than a high-Q circuit which might not select the entire band or group of frequencies in which we are interested.

The curve marked C in Fig. 11 is the one we would obtain with a 50-mh coil, a 2-mfd capacitor and a series resistance of 120 ohms. Compare this curve with curve A. Notice that curve A is considerably sharper than curve C. The ratio of the inductance to the capacity is called the L to C ratio. In a series-resonant circuit a high L to C ratio will give you a sharper resonance curve than a low L to C ratio.

SELF-TEST QUESTIONS

(a) What is a resonant circuit?
(b) What do we mean when we say that the current flowing in the circuit in Fig. 1 is 1 amp?
(c) In a circuit such as the one shown in Fig. 2, why can we not simply add the voltage across the coil and the voltage across the resistor to find the total circuit voltage?
(d) The impedance of a circuit is given as $Z = 50 + j50$; what does the j mean?
(e) In an RC circuit, which part will have the greater voltage across it?
(f) In a series-resonant circuit, how will the phase of the voltage across the various components compare with the phase of the current flowing in the circuit?
(g) What do we mean by the Q of a coil?
(h) When a coil and a capacitor are connected in series, and the frequency of the voltage applied to them is varied, at what point will the current flowing in the circuit reach its maximum value?
(i) What effect on the current flowing in a series-resonant circuit will reducing the resistance in a circuit have?

Parallel-Resonant Circuits

When the source voltage for a resonant circuit is supplied across the coil and capacitor (that is, in parallel with them), as in Fig. 12, we have a

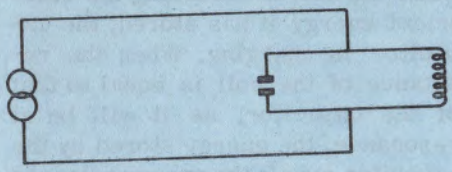


Fig. 12. A parallel-resonant circuit.

parallel-resonant circuit. In a parallel-resonant circuit, as in a series-resonant circuit, the inductive reactance of the coil is exactly equal to and cancels the capacitive reactance of the capacitor. This is essentially where the similarity between the two types of resonant circuits ends. In most respects, a parallel-resonant circuit acts in the opposite way to a series-resonant circuit. Let's investigate the characteristics of this type of resonant circuit and see why it performs as it does.

CIRCUIT CURRENT AND IMPEDANCE

In Fig. 13 we have shown a parallel-resonant circuit connected in series with a 120-ohm resistor across a 120-volt, 500-cycle generator. The coil has an inductance of 100 mh and the capacitor has a capacity of 1 mfd. All the conditions are as they were when we studied the series-resonant circuit. We have connected an ammeter in series with the resistor and the parallel-resonant circuit, a voltmeter across the coil and capacitor combination, and another voltmeter across the resistor.

In this type of circuit you can notice immediately that the current being supplied by the generator is very low. In addition, the voltage across the resistor is very low and nearly the entire source voltage appears across the resonant circuit.

The fact that the current flowing in the circuit is low immediately points out one important fact -- if the current flowing in the circuit is low, the impedance of the circuit must be high. In fact, this is the case; one of the most important characteristics of a parallel-resonant circuit is that at the resonant frequency it acts as a high-value resistance. Notice that this is just the opposite of a series-resonant circuit: at resonance a series-resonant circuit acts as a low resistance.

The fact that the parallel-resonant circuit acts like a high resistance explains why most of the source voltage appears across the resonant circuit and very little voltage appears across the 120-ohm resistor. The

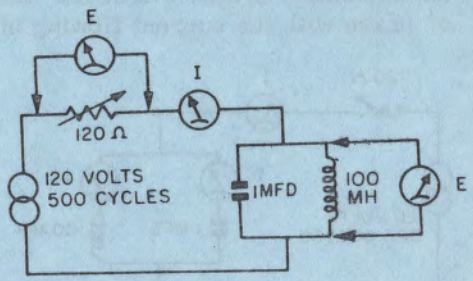


Fig. 13. In a parallel-resonant circuit, the current supplied by the generator is low, and most of the generator voltage appears across the resonant circuit.

120 volts supplied by the generator is simply divided between the resistor and the resonant circuit, with most of the voltage appearing across the higher resistance. Now let's study the parallel-resonant circuit in detail to see why it acts like a high value resistance.

Since the coil and capacitor in the parallel-resonant circuit are connected in parallel, there are two paths or branches through which current can flow. We call the path with the capacitor in it the capacitive branch, and the one with the inductance in it the inductive branch. If we connect an ac ammeter in each branch of the parallel-resonant circuit as shown in Fig. 14, we will discover that although we have a very low current being supplied by the generator, we have a very high current in each branch of the resonant circuit. You might wonder how this could be, but if we consider each branch separately we can see what is happening.

First, in a capacitive circuit we know that the current leads the voltage by 90°; in an inductive circuit the current lags the voltage by 90°. Therefore, the current flowing in the capacitive branch will be 180° out of phase with the current flowing in the inductive branch. The fact that the currents I_1 and I_2 are 180° out of phase means that the capacitor is discharging during one half cycle while the coil stores up electrical energy. During the next half cycle when the coil is releasing the electrical energy it has stored, the capacitor is charging. When the reactance of the coil is equal to that of the capacitor, as it will be at resonance, the energy stored by the capacitor equals the energy released by the coil; and during the other half of the cycle, the energy stored by the coil equals the energy released by the capacitor.

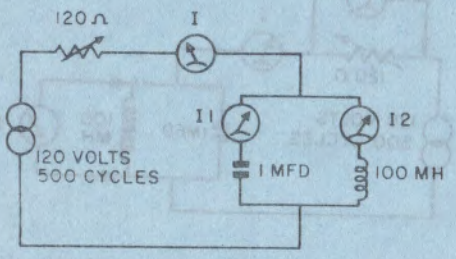


Fig. 11. Although the current supplied by the generator is low, the current flowing in each branch of a parallel-resonant circuit is high.

Thus the coil and the capacitor pass current back and forth to each other inside the resonant circuit. The actual amplitude of the current will depend upon the amount of resistance in the circuit. You know that the coil will have some resistance, and in addition, the leads connecting the coil and capacitor together have some resistance. However, because the resistance is usually kept quite low there can be a very high current flowing back and forth between the coil and the capacitor.

The fact that there is resistance in the circuit means that there will be some energy lost during each cycle. The very low current being supplied by the generator actually replaces the energy lost as heat because of the resistance in the resonant circuit.

The situation in the parallel-resonant circuit may be compared to the pendulum of a clock. The pendulum swings back and forth, and the current does essentially the same thing; it flows out of the coil into the capacitor and then back from the capacitor into the coil. If the

pendulum in a clock were swinging freely, it would lose energy each oscillation due to friction and each arc would be smaller than the previous one; finally, it would come to rest. In a parallel-resonant circuit the current will flow back and forth and get smaller each cycle and eventually drop to zero unless some outside energy is supplied to it. The mechanical drive in the clock supplies the energy to the pendulum to keep it swinging; in the resonant circuit, the generator across the circuit supplies the energy to make up the losses in the circuit. Once the action of the current flowing back and forth in a parallel-resonant circuit has started, it will continue for a number of cycles until all the energy is used up in the resistance in the circuit. Similiarly, the pendulum of a clock will swing back and forth for a number of cycles once it is started in motion even if no additional energy is supplied to it.

The situation we have found in the parallel-resonant circuit exists at all times when a coil and capacitor are connected in parallel in an ac circuit. One feeds energy or current back into the circuit while the other draws current. Therefore, the current supplied by the generator at any instant will be the difference between the two currents. When the reactances are equal, as they are at resonance, then this current becomes the minimum current needed to make up the losses in the parallel-resonant circuit. Because the current does drop to a minimum value at resonance, the parallel-resonant circuit acts like a resistor of high ohmic value and reduces the line current supplied by the generator to a very low value.

At resonance, the inductive and capacitive currents are equal to each other and opposite in phase. The net result is zero current. Since the current is zero, the circuit acts as a high resistance. The current supplied to a parallel-resonant circuit by the generator will be in phase with the generator voltage. The actual resistance of the parallel-resonant circuit can be obtained by measuring the voltage across it and dividing it by the current supplied by the generator. This effective resistance is known as the resonant resistance of the circuit.

There is a resonant voltage step-up in a series-resonant circuit. This is not the case, however, in a parallel-resonant circuit since the coil and the capacitor are connected in parallel. The current flowing between the coil and the capacitor is much higher than the current supplied by the generator. Therefore, we have a resonant current step-up in a parallel-resonant circuit. In a high-Q circuit of the latter type, the current flowing back and forth may be many times the line current.

VARYING R, L, C, AND F

Varying R.

You will remember that all coils have a certain amount of resistance which gives the effect of a resistor connected in series with the coil. This resistance can be changed by changing the size of the wire used to wind the coil while at the same time keeping the inductance of the coil constant.

If we use a circuit like the one shown in Fig. 15 to study the effect of varying the resistance in series with the coil, we will find that with the resistance set at a minimum, the coil current is equal to the capa-

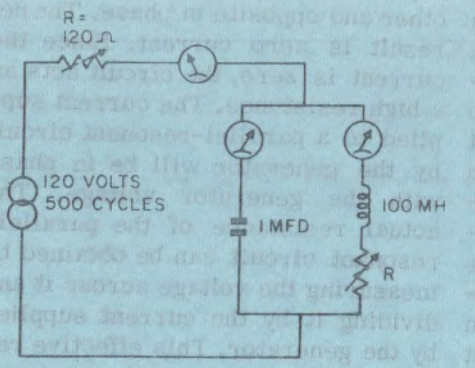


Fig. 15. Increasing R will increase the line current, which means that the resonant resistance of the resonant circuit has decreased.

citor current, and that the line current is very low. If we increase the value of the resistance R, the coil current will decrease slightly and the capacitor current will remain the same, but the line current will increase. This means that the resonant resistance of the parallel-resonant circuit must decrease in order for the line current to increase. From this we can see that the lower the coil resistance in a parallel-resonant circuit, the higher the resonant resistance and the lower the line current will be.

We mentioned earlier that once the current starts flowing back and forth in a parallel-resonant circuit, it will continue for a number of cycles even though the generator voltage may be removed. How quickly the current flowing in the circuit drops to zero depends upon the resistance in the circuit. If the resistance in the circuit is high, the energy in the circuit will be dissipated quickly in the resistor and the current will drop to zero in a few cycles. On the other hand, if the resistance in the circuit is very low, there will be very little energy lost each cycle and the back and forth action of the current may continue for a large number of cycles.

Varying C.

In the parallel-resonant circuit with a 100-millihenry coil, we will obtain resonance at 500 cycles when the capacity in parallel with the coil is 1 mfd. The line current will be minimal at this point.

If we set R to zero and try different values of capacitors in parallel with the coil, recording the line current for each capacitor, we could obtain the data to plot a curve like the one shown in Fig. 16. Notice that at resonance the line current drops to a low value. When the capacity is less than 1 mfd, the current rises until it is about .35 amp at zero capacity. Under these circumstances, with no capacity in parallel with the coil, the current flowing in the circuit will be limited by the inductive reactance of the coil and the amount of resistance in the circuit.

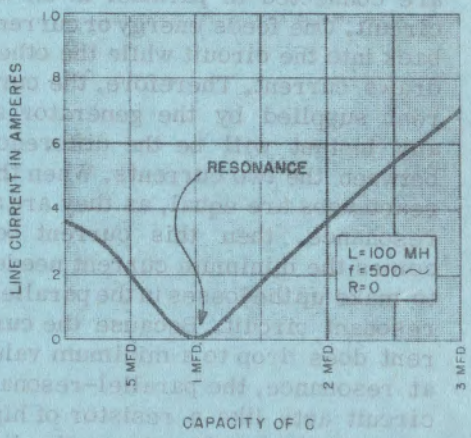


Fig. 16. How the line current varies when the capacity of the capacitor in a parallel-resonant circuit is varied.

When the capacity is reduced to zero, we have a circuit like the one in Fig. 2. However, as capacity is placed in parallel with the coil, the line current begins to drop until finally at resonance it is practically zero.

As the capacity is increased beyond 1 mfd, its reactance decreases, so you will find that the capacitor current will start to increase, the line current will increase, and the coil current will remain essentially unchanged. Here the increase in line current is due to the fact that the capacitor current becomes greater than the coil current and hence part of the capacitor current must be drawn from the line.

When the capacity is less than that required for resonance, the increase in line current is due to the fact that the coil current is greater than the capacitor current and part of the coil current must be drawn from the line.

It is interesting to note that when the capacity in the circuit is .5 mfd, the current is considerably higher than it was when the circuit was at resonance. This is because the capacitive reactance in the circuit is considerably higher than the inductive reactance. If the frequency applied to the circuit were increased, the inductive reactance would increase, and the capacitive reactance would decrease. By increasing the frequency by the correct amount, we could eventually reach the point where the inductive reactance would be equal to the capacitive reactance of the .5 mfd capacitor; once again we would have resonance.

Varying L.

If we put different coils in the circuit, while at the same time keeping the source frequency at 500 cycles,

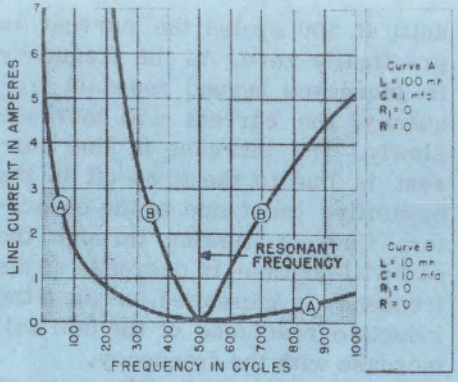


Fig. 17. How the line current varies when the frequency is varied in a parallel-resonant circuit.

we will find that we have an effect somewhat similar to the effect of changing the value of the capacitor. The line current will be increased when the inductance is made either too large or too small for resonance. If the inductance is below the value needed for resonance, the circuit will act exactly as it did when too high a capacity was used; when the inductance is too high for resonance, the circuit will act as it did when the capacity was too low.

Varying F.

In Fig. 17 we have a graph that shows how the line current will vary as the frequency applied to the resonant circuit is changed, if both resistors are set at zero. If we started with 0 cycles, which is dc, we would have a very high current. At this frequency there would be no current through the capacitor, and the inductive reactance of the coil would be zero. The only thing limiting the current flow in the circuit would be the resistance of the coil and of the leads used to connect it to the voltage source. However, as the frequency applied to the circuit increases, the line current drops

until at 500 cycles the current is practically zero. As the frequency is increased beyond resonant frequency, the current will increase slowly. The increase in line current is due to the drop-off in the capacitive reactance of the capacitor. Current flowing through the coil will continue to decrease as the frequency is increased, because the inductive reactance of the coil will increase with the frequency.

At a frequency below the resonant frequency of the circuit, most of the current flows through the coil, and hence the parallel-resonant circuit acts as a coil. Right at resonance the circuit acts as a very high resistance, and above the resonant frequency the current flowing through the capacitor will be greater than the current flowing through the coil; hence, the resonant circuit will act as a capacitor.

The curve marked A in Fig. 17 represents an inductance of 100 mh and a capacity of 1 mfd. This circuit is resonant at 500 cycles, because the inductive reactance of the coil is equal to the capacitive reactance of the capacitor at this frequency. However, if we reduce the inductance to 10 mh and increase the capacity to 10 mfd, we will again have a situation where the inductive reactance is equal to the capacitive reactance at 500 cycles. In other words, a 10-mh coil will form a parallel-resonant circuit with a 10 mfd capacitor at a frequency of 500 cycles. The curve we would obtain by varying the frequency of the voltage applied to the parallel-resonant circuit made up of the 10-mh coil and the 10-mfd capacitor is represented by curve B in Fig. 17. Notice that the current rises much faster on both sides of resonance and drops to zero much more sharply than the curve for the 100 mh coil and the 1 mfd capacitor. We say that curve B is sharper than curve A. Curve A was obtained with one LC ratio: a 100 mh coil and a 1 mfd capacitor. Curve B was obtained with another LC ratio: a 10-mh coil and a 10-mfd capacitor. The LC ratio for curve A is higher than the LC ratio for curve B. A low LC ratio gives a sharp curve. This is an important thing to remember.

A low LC ratio is essential if a parallel-resonant circuit is to be used to separate signals having nearly the same frequency (for example, in radio receivers where stations operating on frequencies close together must be separated). If the resonant curve is sharp, we can tune in the desired signal and reject the undesired signals. However, if the resonant curve is broad, as the curve marked A in Fig. 17, it will be difficult to separate the undesired signals from the desired one.

The Q of a coil is another factor that will effect the sharpness of the resonance curves. A high-Q coil will yield a much sharper response curve than a low-Q coil.

In a series-resonant circuit, we obtain a sharp response curve with a high LC ratio. We have the opposite situation in a parallel-resonant circuit, however: we obtain a sharp curve with a low LC ratio.

SELF-TEST QUESTIONS

(j) How do you distinguish between a series-resonant and a parallel-resonant circuit?

(k) What does a parallel-resonant circuit act like at resonance?

(l) Does the generator supply a current of high value or of

low value to a parallel-resonant circuit?

(m) In circuits such as the one shown in Fig. 13, why will the voltage across a 120-ohm resistor be small?

(n) Does a current of high value or low value flow in the coil and capacitor in a parallel-resonant circuit?

(o) Will increasing the resistance of the coil in a parallel-resonant circuit cause the generator current to increase or to decrease?

(p) If a parallel-resonant circuit is used in a radio receiver to select one signal and reject others, do you want a high LC ratio or a low LC ratio?

Comparison of Series-Resonant And Parallel-Resonant Circuits

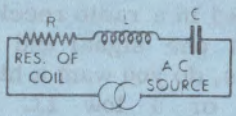
Series-resonant and parallel-resonant circuits are found in every radio and TV receiver and in many other pieces of electronic equipment. Resonant circuits are used in receiving equipment to separate the stations operating on different frequencies and in transmitting equipment in conjunction with vacuum tubes and/or transistors to generate radio frequency signals.

The chart shown in Fig. 18 compares and summarizes the important characteristics of series-resonant and parallel-resonant circuits. Notice that in many cases a series-resonant circuit is the exact opposite of a parallel-resonant circuit. Perhaps the most important characteristics of the two types are the resistance at resonance and the current at resonance. A series-resonant circuit acts as a low resistance at resonance and the current flowing through it will be at its maximum value. On the other hand the parallel-resonant circuit is exactly the opposite, so that at resonance it acts as a very high resistance and the line current flowing through it will be at its lowest value.

RESONANCE CURVES

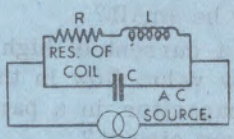
In Fig. 17 you saw that we used a small inductance and a large capacity to obtain a sharp resonance curve with a parallel-resonant circuit. This gave us a low LC ratio. For a sharp resonant curve in a series-resonant circuit you should use a high LC ratio; in other words, you should use a large inductance and a small capacity. This is simply another example of the difference between series-resonant and parallel-resonant circuits. As a technician you will not be called upon to design a series-resonant or a parallel-resonant circuit, but the more you understand about the circuits the better you will be able to maintain the equipment for which you may be responsible.

SERIES-RESONANT CIRCUITS



1. The coil, the capacitor and the AC voltage source are all in series.
2. Resonance occurs when the reactance of L is equal to the reactance of C.
3. At resonance, source current is a *maximum* (very high).
4. At resonance, a series resonant circuit acts like *a resistor of low ohmic value.*
5. At resonance, the voltages across L and C are equal in magnitude but 180 degrees out of phase with each other.
6. At resonance, the same current flows through the entire circuit.
7. At resonance, the voltage across either L or C may be greater than that of the source, giving resonant voltage step-up.
8. At resonance, increasing the value of coil resistance R lowers the circuit current, thereby *lowering* the resonant voltage step-up.
9. Off resonance, the circuit acts like that part which has the *higher* reactance.
   a. Increasing C above its at-resonance value makes the circuit act like a coil.
   b. Reducing C below its at-resonance value makes the circuit act like a capacitor.
   c. Increasing L above its at-resonance value makes the circuit act like a coil.
   d. Reducing L below its at-resonance value makes the circuit act like a capacitor.
   e. Applying a *higher* frequency than the resonant one makes the circuit act like a coil.
   f. Applying a *lower* frequency than the resonant one makes the circuit act like a capacitor.
10. The product LC is constant for any given resonant frequency.
11. Increasing L or increasing C lowers the resonant frequency.
12. Decreasing L or decreasing C raises the resonant frequency.
13. The Q factor of the circuit is essentially equal to the coil reactance divided by the AC resistance of the coil.

PARALLEL-RESONANT CIRCUITS



1. The coil, the capacitor and the AC voltage source are all in parallel.
2. Resonance occurs when the reactance of L is equal to the reactance of C.
3. At resonance, source current is a *minimum* (very low).
4. At resonance, a parallel resonant circuit acts like *a resistor of high ohmic value.*
5. At resonance, the voltages across L, C and the source are all the same in magnitude and phase.
6. At resonance, the currents through L and C are essentially equal in magnitude but are 180 degrees out of phase.
7. At resonance, the current through either L or C is greater than the source current, giving resonant current step-up.
8. At resonance, increasing the value of coil resistance R increases line current, thereby *lowering* the resonant current step-up.
9. Off resonance, the circuit acts like that part which has the *lower* reactance.
   a. Increasing C above its at-resonance value makes the circuit act like a capacitor.
   b. Reducing C below its at-resonance value makes the circuit act like a coil.
   c. Increasing L above its at-resonance value makes the circuit act like a capacitor.
   d. Reducing L below its at-resonance value makes the circuit act like a coil.
   e. Applying a *higher* frequency than the resonant one makes the circuit act like a capacitor.
   f. Applying a *lower* frequency than the resonant one makes the circuit act like a coil.
10. The product LC is constant in any given resonant frequency.
11. Increasing L or increasing C lowers the resonant frequency.
12. Decreasing L or decreasing C raises the resonant frequency.
13. The Q factor of the circuit is essentially equal to the coil reactance divided by the AC resistance of the coil.

Fig. 18. Comparison of series-resonant and parallel-resonant circuits.

DISTINGUISHING BETWEEN SERIES AND PARALLEL-RESONANT CIRCUITS

Sometimes, it is not easy to distinguish between a series-resonant and a parallel-resonant circuit. In Fig. 19A we have shown a series-resonant circuit. A series-resonant circuit is a resonant circuit in which the source voltage has been applied to the coil and capacitor in series. There is no doubt that this is a series-resonant circuit.

In Fig. 19B we have shown a parallel-resonant circuit. The parallel-resonant circuit is a resonant circuit in which the source voltage has been applied to the coil and capacitor in parallel. Again, it is easy to see that this is a parallel-resonant circuit.

Fig. 19C shows two resonant circuits that again look like two parallel-resonant circuits. Here, the secondary is inductively coupled to the primary. Let's look at the primary first. The voltage source is applied to the coil and capacitor in parallel; there is no doubt that the primary is in a parallel-resonant circuit. But how about the secondary? Since the coil and capacitor are connected in parallel you might jump to the conclusion that this is a parallel-resonant circuit, too. Actually, this has no bearing--how the voltage is applied to the circuit determines whether the circuit is a series-resonant or parallel-resonant circuit.

The voltage is induced in the secondary. Actually, some voltages are being induced in each turn of the coil and they act as if they are connected in series, so that the total voltage induced in the secondary is the sum of the voltages induced in each turn. We can compare this to a number of small generators connected in series with the various turns of the coil, and the coil might look like Fig. 19E.

Thus, the voltage induced in the coil is actually applied in series with the turns of the coil rather than in parallel with the coil and the capacitor and could be represented by Fig. 19D (which is the same as Fig. 19A). Therefore, the secondary of the transformer shown in Fig. 19C is a series-resonant circuit and not a parallel-resonant circuit.

You will run into this type of double-tuned circuit in many pieces of electronic equipment. It is often used between two stages in a radio receiver or a television receiver as shown in Fig. 20. Here the primary is connected between the plate of one tube and B+. The secondary is connected between the grid and the cath-

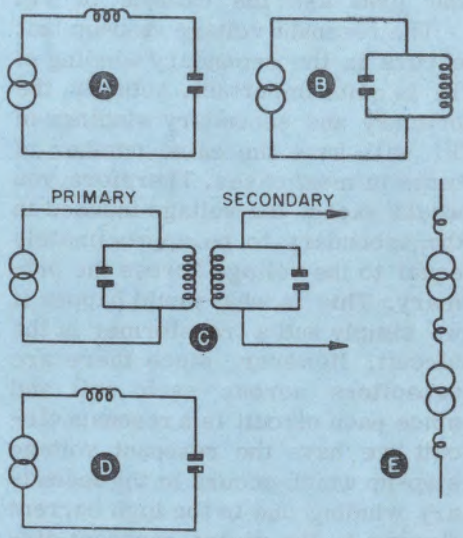


Fig. 19. A series-resonant circuit is shown at A, and a parallel-resonant circuit is shown at B. In C, the primary of the transformer and the capacitor across it form a parallel-resonant circuit, and the secondary of the transformer and its capacitor form a series-resonant circuit.

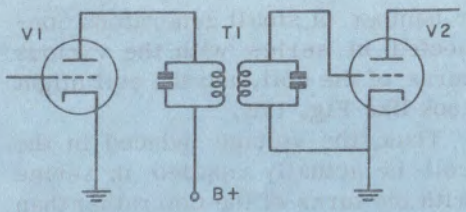


Fig. 20. The primary of T1 is a parallel-resonant circuit, but the secondary is a series-resonant circuit.

ode of the second tube. The tube marked V1 really acts as a generator and supplies the ac signal across the primary of the transformer. A signal is induced in series with the secondary winding, because the secondary is inductively coupled to the primary. Because the coil and capacitor in the secondary form a series-resonant circuit, there is a high current flow with resulting resonant voltage step-up so that this stepped up voltage is applied between the grid and the cathode of V2.

The resonant voltage step-up that occurs in the secondary winding of T1 is quite important. Actually, the primary and secondary windings of T1 will have the same number of turns in most cases. Therefore, you would expect the voltage induced in the secondary to be approximately equal to the voltage across the primary. This is what would happen if we simply had a transformer in the circuit. However, since there are capacitors across each coil and since each circuit is a resonant circuit we have the resonant voltage step-up which occurs in the secondary winding due to the high current flowing in the series-resonant circuit. Thus, there is actually a step-up in voltage occurring in the transformer even though the turns-ratio may be one to one. This means that the signal voltage available between the grid and cathode of V2 will be considerably greater than the voltage between the plate and ground of V1.

SELF-TEST QUESTIONS

(q) Explain the difference between the current flowing in the coil and capacitor in a series-resonant circuit and the current flowing in the coil and capacitor in a parallel-resonant circuit.

(r) Explain the difference between the voltage across the coil and capacitor in a series-resonant circuit and the voltage across the coil and capacitor in a parallel-resonant circuit.

(s) What is the difference between the generator current in a series-resonant circuit and in a parallel-resonant circuit?

(t) How can the voltage across the coil or capacitor in a series-resonant circuit be greater than the source voltage?

(u) What happens if we increase the value of inductance or capacitance in a resonant circuit?

(v) Will the voltage across the coil or the capacitor in a high-Q series-resonant circuit be greater than the voltage across the coil or capacitor in a low-Q series-resonant circuit?

(w) Reducing L below its at-resonance value in a series-resonant circuit makes the circuit act as a capacitor; reducing L below its at-resonance value in a parallel-resonant circuit makes the circuit act as a coil. Explain why this happens.

How Resonant Circuits Are Used

Resonant circuits have many applications. In this section of the lesson we will look into some of the more common uses of resonant circuits in radio and TV. These uses are important because they demonstrate how resonant circuits are used to select one signal from a number of signals of different frequencies.

SELECTING A DESIRED SIGNAL

The antenna connected to a radio or a TV receiver picks up signals from a large number of radio and TV stations. Even the antennas installed especially for television receivers will pick up a certain amount of signal from radio broadcast-band stations. This happens even though the antenna is designed for operation on a much higher frequency than that of the broadcast-band station. Therefore, some means must be provided inside the receiver to select the desired signal and reject the unimportant one. Resonant circuits are used for this purpose.

In Fig. 21 we have shown the input circuit of a radio receiver. The

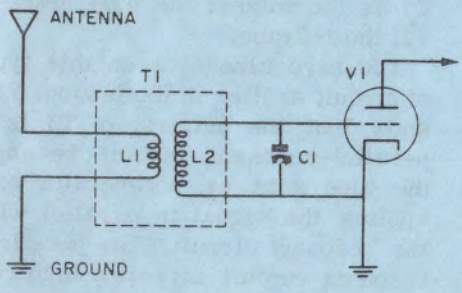


Fig. 21. The input circuit of a typical radio receiver.

signals picked up by the antenna cause a current to flow through the primary winding L1 of T1. T1 is called an antenna coil or transformer because the signals from the antenna are applied to this coil. The secondary L2 of T1 is inductively coupled to the primary so that the current flowing in L1 sets up a magnetic field which cuts L2 and induces a voltage in it. Remember that when a voltage is induced in a coil in this way, there is a certain amount of voltage induced in each turn of the coil. The voltage induced in the coil acts like a number of generators connected in series with the coil. Thus L2 and capacitor C1 form a series-resonant circuit at some frequency within the broadcast band.

Notice the symbol used for the capacitor C1. This symbol indicates that the capacitor is variable. Thus, by changing the setting of C1, the frequency at which the combination of L2 and C1 is resonant can be changed.

Let us suppose that the antenna is picking up two signals of equal amplitude or strength, one having a frequency of 500 kc and the other having a frequency of 800 kc. If the combination of C1 and L2 is resonant at 800 kc (C1 and L2 thus forming a series-resonant circuit), there will be a high 800-kc current through L2 and C1, with resultant step-up voltages appearing across L2 and C1. These voltages are applied between the grid and the cathode of V1 to be amplified by this tube.

At the same time there is a 500-kc signal being picked up by the antenna. This will flow through the primary of transformer T1 and will

induce a certain voltage in L2. Since the combination of L2-C1 is not resonant at 500 kc, the impedance of this series circuit will be much higher at 500 kc than it was at 800 kc. This means that the 500-kc current flowing through the series circuit will be low so that voltage developed across L2 and across C1 by this current will be low. Therefore, the 500-kc signal applied between the grid and the cathode of V1 will be much lower in amplitude than the 800-kc signal. Thus, although one resonant circuit is not able to reject the 500-kc signal completely, the amplitude of this signal (when applied between the grid and the cathode of V1) is lower than the amplitude of the desired 800-kc signal that is applied to this tube.

Better selectivity can be obtained in a receiver by using several resonant circuits. If each circuit is tuned to the desired frequency, the difference in signal strength between the desired and the undesired signals will become greater. If enough resonant circuits are used the only signal actually heard in the output of the receiver will be the signal from the desired station.

I-F Transformers.

Most modern radio and television receivers use the superheterodyne principle. In the superheterodyne receiver the signal is picked up by the antenna and fed to a stage called a mixer or first detector. Here, the signal is mixed with a signal generated by the oscillator stage. The two signals mixed together produce two new signals, one equal to the sum of the two frequencies and the other equal to the difference of the two. Both new signals contain the modulation on the original signal. In a superheterodyne receiver we use the difference-frequency signal. In the output circuit of the mixer stage we use a transformer called an intermediate frequency transformer (usually abbreviated as an i-f transformer). This transformer is tuned to resonance at the difference frequency. One or more amplifier stages (called i-f amplifiers) are used to amplify the difference signal. I-F transformers are used between the mixer and the various stages in the i-f amplifier and between the last i-f amplifier stage and the stage called the second detector. The latter separates the audio or picture signals from the rf carrier. Resonant circuits are used in i-f transformers.

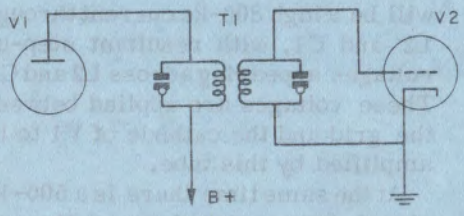


Fig. 22. Coupling between the mixer and the i-f tube in a superheterodyne receiver.

The schematic of a circuit used between the mixer and first i-f stage in a superheterodyne receiver is shown in Fig. 22. The tube marked V1 is the mixer; the tube marked V2, the i-f tube.

You have already seen this type of circuit earlier in the lesson. You know that the primary of T1 is a parallel-resonant circuit because the tube acts as a generator and applies the signal in parallel with the resonant circuit. This parallel-resonant circuit acts as a high resistance at the resonant frequency and the voltage developed by the tube will be high. At frequencies

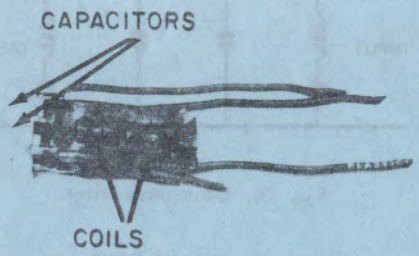


Fig. 23. The inside of an i-f transformer.

other than the resonant frequency, the primary circuit of T1 does not act as a high resistance; as a matter of fact, it acts as a fairly low impedance, so the voltage developed at these frequencies by V1 is low.

The primary of T1 is inductively coupled to the secondary winding so that the secondary circuit is a series-resonant circuit. Again at the resonant frequency, a high current flows and there is considerable resonant voltage step-up across the coil and across the capacitor. These stepped-up voltages are applied between the grid and the cathode of the i-f stage.

A typical i-f transformer is shown in Fig. 23. Notice that the two coils are placed near each other so that the primary and secondary are inductively coupled together. At the top of the transformer are two trimmer capacitors. The adjusting screws on these capacitors can be reached through holes in the top of the i-f transformer can or shield and can be adjusted for exact resonance after they have been installed in the circuit.

A modern superheterodyne receiver uses at least two i-f transformers like the one shown in Fig. 23. The selectivity of two transformers in conjunction with the selectivity obtained in other circuits will make the receiver selective enough so that it will pick up the desired signal even in the crowded broadcast band and in most cases reject the signals from undesired stations.

High-Frequency Circuits.

In some high frequency applications you might find a circuit like the one shown in Fig. 24. The symbol beside the coil indicates that the coil has a slug which can be adjusted in and out of the coil. This will change the inductance of the coil.

Although no capacitor is shown in the circuit, the circuit is actually a parallel-resonant circuit. The tube has a certain capacity between plate and ground, and this capacity will be in parallel with the coil. At high frequencies this capacity, along with the coil, is all that is needed to form a resonant circuit. Circuits of this type are frequently found in television receivers.

In some applications the coil may consist of less than one turn of a flat ribbon-type material such as

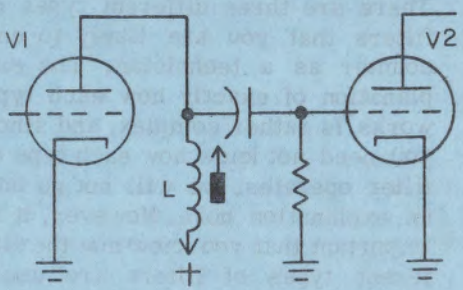


Fig. 24. Coil L in the plate circuit of V1 along with the circuit capacities form a parallel-resonant circuit.

shown in Fig. 25. This type of coil is used in UHF TV circuits and although the inductance in the circuit is extremely small, due to the fact that the circuit must operate at several hundred megacycles, this inductance is all that is required. As a matter of fact, in resonant circuits designed for UHF operation, the problem is not in getting the needed inductance and capacitance, but rather in keeping the inductance and capacitance low enough to produce resonance at the ultra-high frequency desired.

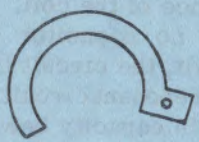


Fig. 25. A single turn of flat ribbon is all the coil that is needed in UHF circuits.

HOW DIFFERENT TYPES OF FILTERS ARE USED

Another important use of resonant circuits is in the design of filters. There are three different types of filters that you are likely to encounter as a technician. The explanation of exactly how each type works is rather complex, and since you need not know how each type of filter operates, we will not go into an explanation here. However, it is important that you know how the different types of filters are used.

Low-Pass Filters.

In Fig. 26 we have shown a schematic diagram of a low-pass filter, which is a filter that will allow signals below a certain frequency to

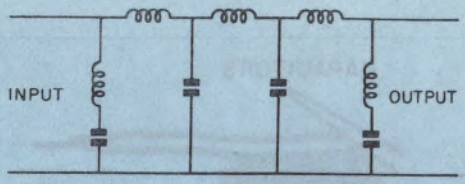


Fig. 26. A low-pass filter.

pass through it with little or no attenuation, which means weakening of signals above this specific frequency. For example, if a low-pass filter is designed to pass frequencies below 10 megacycles, it will pass all frequencies from zero cycles per second, which is dc, up to 10 mc with little or no opposition. However, a signal with a frequency of 15 mc, or 25 mc, or in fact any frequency above 10 mc, will encounter a great deal of opposition in going through the filter.

High-Pass Filters.

A high-pass filter is designed to cut off all frequencies below a certain frequency and allow signals above this frequency to pass through with little or no attenuation. A schematic of a typical high-pass filter is shown in Fig. 27.

High-pass filters are often used on TV receivers to eliminate interference from stations operating on frequencies below the television channel. High-pass filters designed for this purpose are available commercially.

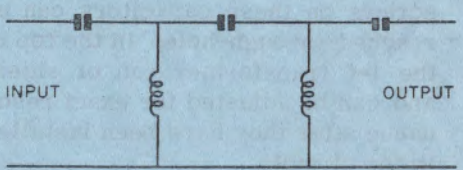


Fig. 27. A high-pass filter.

Band-Pass Filters.

Another type of filter is shown in Fig. 28. This type of filter, called a band pass filter, allows a certain band of frequencies to pass through it with little or no attenuation but offers considerable opposition to signals above and below the frequency of the band to be passed.

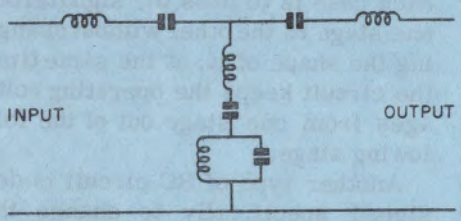


Fig. 28. A band pass filter.

For example, if a band pass filter is designed to have a band width of 2 megacycles, and the center of the pass band is 10 megacycles, then the band pass filter will pass frequencies from 9 mc to 11 mc with little or no attenuation. However, a signal having a frequency of 7 mc, which is below the pass band, or a signal having a frequency of 15 mc, which is above the pass band, will encounter considerable opposition going through the band pass filter.

SUMMARY

In this section of the lesson we have covered a few of the most important uses of resonant circuits. Resonant circuits are used in radio and TV receivers to select one desired signal and reject others. Both series-resonant and parallel-resonant circuits are used in the input stages of a receiver. They are also used between the mixer and i-f stages and between the i-f stage and the second detector.

Resonant circuits are used in filters. A low-pass filter is a filter which will pass frequencies below a certain frequency with little or no attenuation but offers high attenuation to signals above this frequency. A high-pass filter is a filter that will offer little or no attenuation to signals above a certain frequency, but offers high opposition or attenuation to signals below this frequency. A band pass filter will pass a certain band of frequencies, but attenuate signals either above or below the band of frequencies which it is designed to pass.

SELF-TEST QUESTIONS

(x) Is the resonant circuit made up of C1 and L2 in Fig. 21 a series-resonant circuit or a parallel-resonant circuit?
(y) What is a low-pass filter?
(z) What is a high-pass filter?
(aa) What is a band pass filter?
(ab) What type of circuit is used in making up filters?

RC Circuits

Another type of circuit that is extremely important in electronics work is the RC circuit, so called because it contains resistance and capacity. There are several types of RC circuits.

An RC circuit is used as a coupling circuit. This type of circuit is designed to pass a signal through it without changing the shape of the signal. Circuits of this type are used where an ac signal is mixed with dc. RC coupling circuits are widely used in the audio sections of radio and television receivers between the various stages. An RC coupling circuit used between two tubes is shown in Fig. 29A and an RC coupling circuit used between two transistor stages is shown in Fig. 29B. The purpose of the coupling circuit in each case is to pass the signal from one stage to the other without changing the shape of it; at the same time the circuit keeps the operating voltages from one stage out of the following stage.

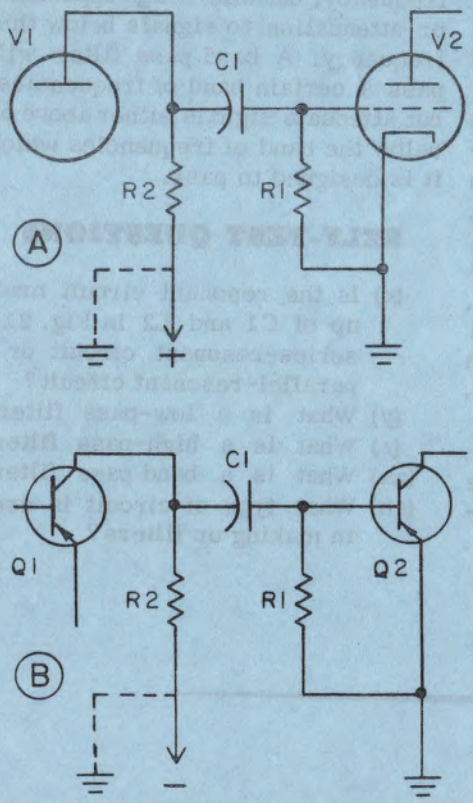


Fig. 29. RC coupling circuits used between tube and transistor stages.

Another type of RC circuit is designed specifically to change the shape of the signal applied to it. This type of circuit is used because the signal being fed through the RC circuit may be used to control the following stage. The shape of the signal may not be the best possible shape to control the stage; by means of a suitable RC circuit, the shape of the wave can be altered. In this section we will study both coupling and wave-shaping circuits, and you will see what they look like, how they work, and where each type is found.

RC COUPLING CIRCUITS

You will run into RC circuits most frequently between stages where they are used to feed the signal from one stage to the next. Typical RC coupling circuits are shown in Fig. 29. The RC coupling circuit in both cases consists of C1 and R1. These are the two components that you will be most concerned with in determining the characteristics of this type of circuit.

The tube V1 in Fig. 29A and the transistor Q1 in Fig. 29B act essentially like an ac generator in RC coupling circuits. One end of re-

sistor R2 is connected to the tube in A and to the transistor in B. The other end is connected to the power supply. However, as far as the ac signal is concerned the end of R2 which is connected to the power supply is in effect connected to ground, because there is a large capacity in the power supply output connected between B+ and ground. This capacitor is so large that it has a very low reactance at all signal frequencies. Therefore the first stage, which is V1 in Fig. 29A and Q1 in Fig. 29B, supplies the voltage to resistor R2. The resistor acts like it is connected between the tube or transistor and ground.

An equivalent circuit of the coupling network is shown in Fig. 30. Here we have represented the tube or transistor as a generator with R2 connected across it. Notice that C1 and R1 are connected in series with each other and this combination is connected in parallel with the resistor R2. The purpose of the coupling network C1-R1 is to feed the signal that is across R2 to the following stage, V2 in Fig. 29A and Q2 in Fig. 29B. If the reactance of C1 is low enough, it will act as a short circuit at signal frequencies so R1 will in effect be connected in parallel with R2. When this situation exists, all the voltage available at the generator output will appear across R1. In other words the voltage appears between the grid and cathode of V2 in Fig. 29A and between the base and emitter of the transistor in Fig. 29B.

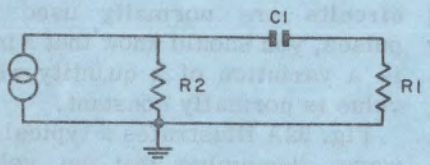


Fig. 30. The equivalent circuit of the RC coupling network shown in Fig. 29.

Capacitor C1 and resistor R1 are in series and they form a voltage divider network. Part of the voltage developed across R2 will be dropped across C1 and part of it across R1. The more voltage there is across R1 the more voltage we have available to drive the second stage. It is therefore important that the reactance of C1 be kept as low as possible in comparison with the resistance of R1. However, regardless of how large the capacitor C1 is, its reactance will eventually become high enough at some low frequency so that an appreciable part of the voltage developed across R1 is lost across C1. At some frequency the reactance of C1 will be equal to the resistance of R1. When this situation occurs 70.7% of the voltage appearing across R2 will be present across R1. You might expect only 50% of the voltage to appear across R1. However, 70.7% is correct because the voltage across R1 is not in phase with the voltage across C1. If the frequency is made still lower, then the percentage of voltage appearing across R1 will be lower.

When the voltage across R1 drops to 70.7% of the generator output, the current flowing through R1 will be only 70.7% of the maximum it would be with the full voltage across R1. When the voltage and current across R1 drop to 70.7%, the power across R1 will decrease to 50%. This point is called the "half-power" point. The amplifier is considered satisfactory in most cases as long as the output does not drop below this point.

Since C1 and R1 form a voltage divider network, we can keep the frequency at which the reactance of

C1 becomes a problem to a fairly low value by making R1 as large as possible. In the tube circuit shown in Fig. 29A, R1 is called a grid leak. Its value is relatively unimportant and a comparatively large resistor can be used. Therefore, even with a fairly small capacitor for C1, the resistance of R1 does not have much importance except at very low frequencies. On the other hand, making R1 too large will upset the operating voltages in the transistor in the circuit shown in Fig. 29B. In fact, the transistor itself affects the circuit so that there is a maximum value resistor that can be used; it is much lower than that used in the tube stage. The capacitor C1 must be of a much higher capacity in the transistor circuit than in the tube circuit to keep its reactance from becoming high enough to drop an appreciable percentage of the voltage.

Capacitor values from .01 mfd to .05 mfd are typical in tube circuits such as in Fig. 29A. In transistor circuits the value of C1 will often be 10 mfd or more.

The importance of avoiding this voltage division can be seen if you consider what happens to signals of different frequencies when they are amplified by the amplifier. If a signal voltage of 1 volt and a frequency of 1000 cycles appears across R2, almost the full 1 volt will appear across R1. But, at a frequency of 100 cycles, somewhat less than 1 volt will appear across R1; at a frequency of 10 cycles, even less will appear across R1. This means that the amplifier will not amplify signals of different frequencies equally. When this situation exists, we say we have frequency distortion. In the average radio receiver, a small amount of frequency distortion is not objectionable, but in high-fidelity equipment and in TV equipment, this type of distortion must be kept at a minimum if satisfactory results are to be obtained.

For the present the important thing you should remember is that an RC coupling circuit has a long time constant. Remember that capacitor C1 and resistor R1 are in series, but that at most frequencies the reactance of C1 is so low compared to the resistance of R1 that it acts as a short circuit and can be ignored. However, at very low frequencies the reactance of this capacitor is appreciable. We will discuss this situation in more detail when you study vacuum tubes and amplifiers.

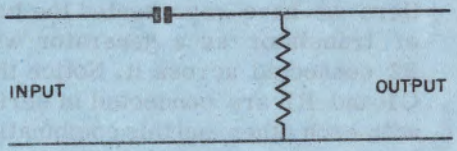


Fig. 31. An RC differentiating circuit.

RC DIFFERENTIATING CIRCUITS

Differentiating circuits are found in TV receivers and in many other pieces of electronic equipment. Fig. 31 shows a circuit of this type -- notice that it looks like a coupling circuit. However, the latter has a long time constant, whereas a differentiating circuit has a short time constant. Because differentiating circuits are normally used with pulses, you should know that a pulse is a variation of a quantity whose value is normally constant.

Fig. 32A illustrates a typical sine wave. Remember that the voltage starts at zero, builds up to a maximum and drops back to zero.

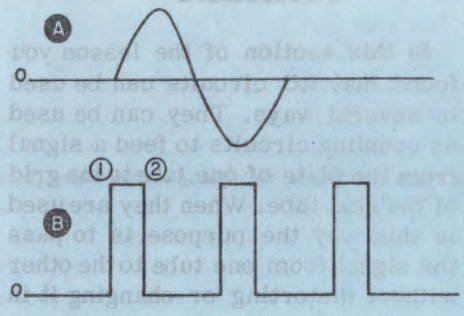


Fig. 32. A single cycle of a sine wave is shown at A, and a group of three pulses is shown at B.

A series of three positive-going pulses is shown in Fig. 32B. Notice that the signal voltage is zero, jumps instantly to its maximum value at point 1, remains constant from point 1 to point 2, and finally drops to zero again at point 2. Let's see what will happen if a pulse of this type is fed to a differentiating circuit such as the one in Fig. 31.

The value of R and of C in the differentiating circuit are chosen with a short time constant so that the capacitor charges and discharges quickly. As the leading edge of the pulse (which we have marked as 1) hits the capacitor there is an immediate current flow through the resistor to charge the capacitor. Since the capacitor has no charge on it at this instant, the current flow as well as the voltage developed across the resistor will be high. As the pulse maintains its constant value, the capacitor charges rapidly, the current flowing in the capacitor decreases and the voltage developed across the resistor falls off. Finally, the capacitor is fully charged, no additional current is flowing and the voltage across the resistor drops to zero.

The capacitor must discharge when the pulse drops from its peak amplitude at point 2 to zero. At the instant the applied voltage pulse disappears the capacitor is charged, although there is no longer a pulse across it. Then it starts to discharge through the resistor and a high current flows through the resistor. Instantly, there is a high voltage across it. The current flows in the opposite direction from that in which it flowed while the capacitor was charging, so the pulse appears in the opposite direction. As the capacitor becomes discharged, the current flowing drops gradually to zero so that the voltage appearing across the resistor also drops to zero.

The reaction of a differentiating circuit to a series of pulses is shown in Fig. 33. At A we have shown the pulse and below it at B the output voltage that will be obtained across the resistor as the pulse varies to a maximum and drops back to zero again.

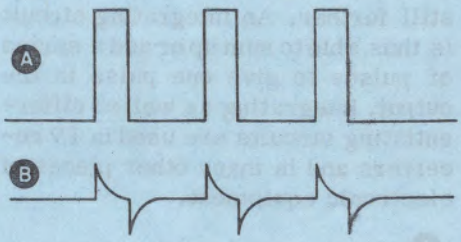


Fig. 33. Input and output signals applied to a differentiating circuit.

Differentiating circuits work in this way because they have a short time constant. The capacitor is able to charge and discharge rapidly, and therefore a double-pointed pulse as shown in Fig. 33 is obtained when a pulse is applied to the input of this type of circuit.

RC INTEGRATING CIRCUITS

A typical RC integrating circuit is shown in Fig. 34. Notice that the parts are connected in a way opposite from that in which they were connected in the differentiating circuit, and that a long time constant rather than a short time constant is used.

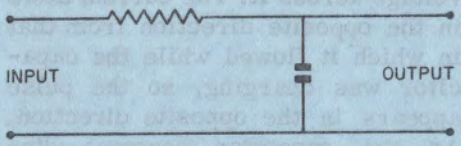


Fig. 34. An integrating circuit.

Fig. 35 illustrates the action of an integrating circuit. The capacitor begins to charge as the first pulse strikes the circuit; it starts to discharge after the first pulse passes but does not discharge completely before the second pulse arrives due to the long time constant. After the second pulse the capacitor starts to discharge again until the third pulse arrives -- then it charges still further. An integrating circuit is thus able to sum up or add a series of pulses to give one pulse in the output. Integrating as well as differentiating circuits are used in TV receivers and in many other pieces of electronic equipment.

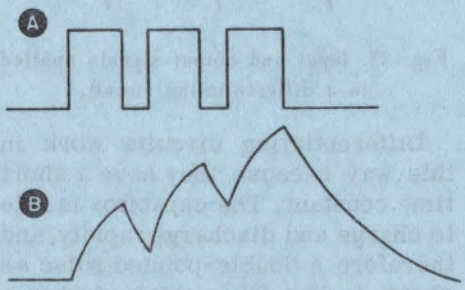


Fig. 35. Integrating circuit action on a series of pulses.

SUMMARY

In this section of the lesson you found that RC circuits can be used in several ways. They can be used as coupling circuits to feed a signal from the plate of one tube to the grid of the next tube. When they are used in this way the purpose is to pass the signal from one tube to the other without distorting or changing it in any way.

RC circuits are also used as differentiating circuits. A differentiating circuit is a circuit that develops a sharp positive and negative pulse from a single pulse. If the pulse supplied to the circuit is a positive-going pulse, which is what we call the pulse shown in Fig. 32B, then the output will be a positive pulse followed by a negative pulse. If the input signal is a negative-going pulse, then the output will be a sharp negative pulse followed by a sharp positive pulse.

An integrating circuit is a circuit that has a long time constant and adds together a number of separate pulses to produce one large pulse in the output.

SELF-TEST QUESTIONS

(ac) What is the purpose of an RC coupling circuit?

(ad) Is the reactance of the coupling capacitor likely to become a problem at high, low, or medium frequencies?

(ae) What do we mean by the half-power point?

(af) What do we mean by frequency distortion?

(ag) What is a differentiating circuit?

(ah) What is an integrating circuit?

LOOKING AHEAD

In this lesson you have seen how resistors, coils, and capacitors are used together to form a number of different types of circuits. By this time you have probably realized the importance of these three components. Before leaving this lesson it is worthwhile to stop and consider the fact that we have all three of these quantities in every circuit.

Even a piece of straight wire has a certain amount of resistance, a certain amount of capacity between it and nearby objects, and also a small amount of inductance. If the frequency of the signal running through the wire is high enough, even these small amounts of resistance, capacity, and inductance may be large enough to merit consideration.

We have brought up this point now because you will soon be working on, repairing, and replacing circuits in equipment which operates at very high frequencies. Because the resistance, capacity, and inductance in circuits operating at these high frequencies is so important, replacement parts should be put as closely as possible in the position occupied by the original part.

In the following lesson you will study additional components that will be important in your electronics career: vacuum tubes, transistors, complete stages and signals. You will also learn how the value of parts used in a circuit affects the performance of the stage.

There are a number of schematic diagrams in this lesson. If you study carefully the diagrams which appear in earlier lessons, complex diagrams in later lessons will not present a problem for you. Difficulties will occur if you wait until later lessons to trace circuits on complex diagrams.

ANSWERS TO SELF-TEST QUESTIONS

(a) A resonant circuit is one in which the inductive reactance cancels the capacitive reactance.

(b) We mean that the rms value or the effective value of the ac current flowing in the circuit is 1 amp. The ac current would have the same heating effect as 1 amp of dc. Remember that an ac current actually drops to 0 twice each cycle and reaches peak values approximately 1.4 times the effective or rms value.

(c) We cannot add the voltages because they are not in phase. The voltage across the resistor will be in phase with the current, whereas the voltage across the coil will lead the current by 90°. We must add these two voltages by means of vectors.

(d) In the expression "j50", the j indicates a reactive component; the 50 (for ohms) represents a reactance rather than a resistance. The plus sign in front of the j means that the reactance is inductive. A minus sign in front of the j indicates capacitive reactance.

(e) The voltage across the parts in an RC circuit will depend upon the parts themselves. If the reactance of the capacitor is greater than the resistance of the resistor then the voltage across the capacitor will be greater than the voltage across the resistor. On the

other hand, if the resistance of the resistor is higher than the reactance of the capacitor, the voltage across the resistor will be greater than the voltage across the capacitor.

(f) Across the resistor the voltage will be in phase with the current; across the coil it will lead the current by 90°; across the capacitor it will lag the current by 90°.

(g) The Q of a coil is equal to the inductive reactance of the coil divided by the resistance of the coil. It is indicative of the worth of the coil, which is supposed to have inductive reactance with little or no resistance. Since the coil is wound with wire, however, it will have some resistance. The coil will act more like a resistor as this resistance increases. Therefore, a high-Q coil is better than a low-Q coil.

(h) The current will reach its maximum value when the inductive reactance of the coil cancels the capacitive reactance of the capacitor. When this happens we have a series-resonant circuit.

(i) Reducing the resistance in a series-resonant circuit will cause the current flowing in the circuit to increase. A higher resonant voltage will appear in turn across the coil and the capacitor. The voltage which appears across the resistor will remain the same because the increase in current will be counteracted by the reduction in resistance. Thus, the entire generator voltage will appear across the resistor.

(j) The distinction between a series-resonant circuit and a parallel-resonant circuit lies in the way in which the voltage is applied to the coil and the capacitor. If it is applied to the coil and the capacitor in series, the circuit is series-resonant; if it is applied to the coil and the capacitor in parallel, the circuit is parallel-resonant.

(k) A high value resistance.

(l) The generator connected across a parallel-resonant circuit will supply a current of low value because the high resistance of this type of circuit limits the current which can flow.

(m) The voltage across the resistor will be small because the resistor is in series with the parallel-resonant circuit. Most of the voltage will be dropped across the higher resistor. A parallel-resonant circuit has a very high resistance at resonance and most of the voltage will be dropped across it. Consequently, there will be very little voltage across the 120-ohm resistor.

(n) In a parallel-resonant circuit, a high value current flows in the coil and in the capacitor. These two currents are 180° out of phase. Energy stored in the capacitor flows out of the capacitor into the coil, where it is stored, and then flows from the coil back into the capacitor. This back-and-forth flow of current reaches a very high value. Even though the current actually supplied by the generator is low, it is enough to make up for losses

in the resonant circuit due to resistance in the coil and in the wires connecting the coil and the capacitor together.

(o) Increasing the resistance of the coil in a parallel-resonant circuit causes the generator current to increase. More losses occur as a result of increased resistance, and the generator supplies more current to make up for these losses.

(p) A low LC ratio gives a sharper curve such as curve B in Fig. 17. This type of curve is required in order to select one station and reject another. A broad curve such as curve A of Fig. 17 would be unsuitable because stations operating close to the desired station would not be rejected.

(q) In a series-resonant circuit the same current flows in the coil and in the capacitor. As a matter of fact, since the generator, resistance, coil and capacitor are all in series in a series-resonant circuit, the same current must flow through all these components. On the other hand, in a parallel-resonant circuit the current through the coil and capacitor are essentially equal in magnitude, but they are 180° out of phase.

(r) In a series-resonant circuit, the voltage across the coil will be equal to but 180° out of phase with the voltage across the capacitor. In a parallel-resonant circuit the coil and capacitor are connected in parallel and the voltage across the two will therefore be the same.

(s) The generator current in a series-resonant circuit will be very high because this circuit acts as a low resistance. The generator current in a parallel-resonant circuit will be very low because this circuit acts as a high resistance.

(t) The inductive reactance of the coil in a series-resonant circuit cancels the capacitive reactance of the capacitor. Therefore the only factor that limits current flow in the circuit is the resistance in the circuit. This results in a very high current flow. The current flowing through the coil and through the capacitor produces a voltage drop across these components which will be equal to the product of the current times the reactance of the particular part. This product may be greater than the source voltage. The voltage across the coil and across the capacitor are 180° out of phase so that they cancel each other and the entire generator voltage will appear across the resistance in the circuit.

(u) Increasing the value of L or C in a resonant circuit will reduce the resonant frequency.

(v) Yes, the voltage across the coil and capacitor in a high-Q series-resonant circuit will be greater than the voltage across the coil and capacitor in a low-Q series-resonant circuit. This is due to the fact that a higher current will flow in a high-Q circuit which, all other factors being equal, will produce a greater voltage across the coil and across the capacitor.

(w) When we reduce L below its at-resonance value in a series-resonant circuit, the inductive reactance will be less than the capacitive reactance. Therefore the net reactance in the circuit will be capacitive - in other words the inductive reactance cannot completely cancel out the capacitive reactance. It will subtract from it but there will still be capacitive reactance left over, and the circuit will act as a capacitor. The current flowing through the circuit will lead the voltage. On the other hand, when we reduce L below its at-resonance value in a parallel-resonant circuit, the inductive reactance will be less than the capacitive reactance and more current will flow through the lower reactive branch. The net result will be that the capacitive current cannot completely cancel out the inductive current. Therefore, the circuit will act as inductance and the voltage will lead the current.

(x) The resonant circuit is a series-resonant circuit because the voltage is induced in series with the turns of L2. Therefore, the voltage is applied in series with the coil and the capacitor.

(y) A low-pass filter is a filter designed to pass signals below a certain frequency and reject all signals above that frequency.

(z) A high-pass filter is a filter designed to pass all signals above a certain frequency and reject signals below that frequency.

(aa) A bandpass filter is a filter designed to pass a certain band of frequencies with little or no attenuation. It will reject or offer considerable opposition to frequencies above and below the band it is designed to pass.

(ab) Various combinations of series-resonant and/or parallel-resonant circuits are used in making up filters.

(ac) An RC coupling circuit is used to transfer a signal from one stage to another without changing the shape of the signal.

(ad) At low frequencies.

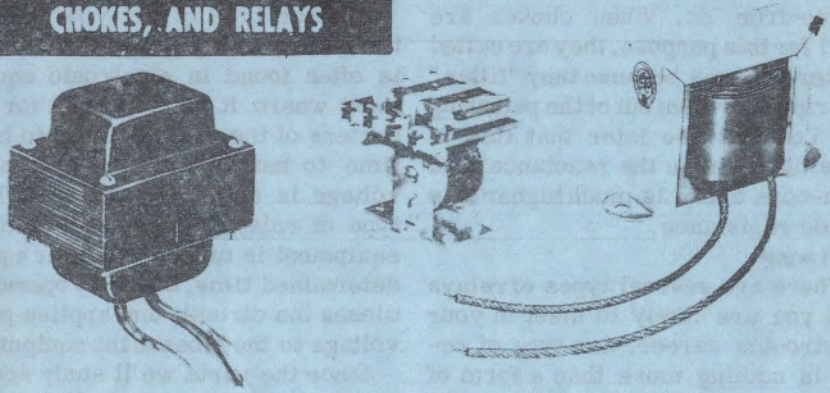
(ae) The half-power point is the frequency at which 70.7% of the voltage appears across the resistor in an RC coupling circuit. At this frequency the current will also have dropped to 70.7% of its maximum value so that the power will be down 50% of its maximum value.

(af) Frequency distortion occurs when the amplifier does not amplify equal signals of different frequencies.

(ag) A differentiating circuit is an RC coupling circuit with a short time constant. A circuit of this type will produce sharp spikes in the output which can be used for controlling stages in a TV receiver.

(ah) An integrating circuit is a circuit with a long time constant that will build a series of pulses up into a single pulse.

TRANSFORMERS, IRON-CORE CHOKES, AND RELAYS



In this lesson we will take up three very important parts which all operate on magnetic principles; these are: transformers, iron-core chokes and relays.

Transformers.

You already have an idea of how important transformers are. Transformers are used on ac power lines either to step-up or to step-down the voltage. They are used in electronic equipment to supply the high voltage needed to operate the plates of the various tubes in the equipment and to supply the low voltage to heat the tubes. They are used in transistorized equipment to reduce the power line voltage to the voltage required by the transistors.

Transformers have uses other than supplying electric power. They are used in coupling circuits to transmit an audio signal from one stage to another. They are also used in what are called "matching" circuits to connect a device of one impedance to a device of another impedance. An example of this is the output transformer in a radio receiver, which is used to couple the low-impedance speaker to the higher impedance output tube or transistor that drives the speaker. If it were not for the transformer it would be difficult to get enough power from the tube or transistor to drive the speaker.

Transformers are also used in television receivers to transfer the power from the sweep circuits to the deflection yoke. The deflection yoke is used around the neck of the picture tube to move the electron beam over the face of the picture tube to reproduce the television picture. If it were not for transformers, it would be difficult to get the power needed into the deflection yoke to move the beam over the face of the picture tube.

Iron-Core Chokes.

Iron-core chokes are found most frequently in power-supply equipment. Chokes are used to help smooth the pulsating dc found at the output of a rectifier into pure, ripple-free dc. When chokes are used for this purpose, they are called "filter" chokes because they "filter" the ripple or hum out of the pulsating dc. You will see later that this is possible because the reactance of an iron-core choke is much higher than the dc resistance.

Relays.

There are several types of relays that you are likely to meet in your electronics career. One type of relay is nothing more than a form of automatic switch. The relay can be made either to close or to open the switch when power is applied to it.

There are also other types of relays; for example, some are used to protect circuits. This type is adjusted so that if the current flowing through it exceeds a certain value, the relay will automatically open the circuit, thus protecting the device from an overload.

Another type of relay is called a time-delay relay. This kind of relay is often found in electronic equipment where it is important for the heaters of the various tubes to have time to heat before the high plate voltage is applied to the tube. This type of relay is energized when the equipment is turned on. After a predetermined time, the relay operates, closes the circuit, and applies plate voltage to the tubes in the equipment.

Since the parts we'll study are all magnetic devices, before we look into any of them, we will review what you have already learned about magnetic circuits and learn some additional facts about these circuits.

Magnetic Circuits

As we learned previously when we studied magnetic circuits, we can compare them with electric circuits. The force that drives the flux through a magnetic circuit is the magnetomotive force. This force can be compared to the electromotive force that drives current through an electric circuit. The flux that is driven through the magnetic circuit resembles the current that is driven through an electric curcuit.

The opposition to the flux through the circuit can be compared to resistance in an electrical circuit, and is called reluctance.

MAGNETIC UNITS

There are units set up to measure many of the quantities encountered in magnetic circuits. It is not important for you to remember these units, so do not try to memorize them. We are presenting them here, however, so that you will have seen these terms and will have an idea of what they are when you run into them in the future. After you have completed your YRS course, you will have to keep abreast with new developments. In reading the literature on new developments in the electronics field, it is quite possible that you will run into many of these terms.

Units of Magnetomotive Force.

The magnetomotive force is expressed in terms of ampere-turns. If a current of 1 ampere flows through a coil having one turn, the magnetomotive force developed is 1 ampere-turn. If the coil had two turns, then the magnetomotive force would be 2 ampere-turns, and if a current of 2 amperes flows through a two-turn coil, the magnetomotive force will be 4 ampere-turns.

The ampere-turn is an entirely satisfactory term for use in expressing the magnetomotive force of an electromagnet. However, it is not suitable for use with permanent magnets, and for this reason, another unit of magnetomotive force is used. This unit is the gilbert. The gilbert is slightly smaller than the ampere-turn. To convert ampere-turns to gilberts, you multiply the number of ampere-turns by 1.25.

The magnetomotive force is the total force acting throughout the length of the entire magnetic circuit. Sometimes we want to express the magnetic force in terms of the magnetomotive force per centimeter. (The centimeter is a metric unit of measurement. There are about 2.5 centimeters in an inch.) It may be given as gilberts per centimeter. Then, if the length of the magnetic circuit is six centimeters and the magnetomotive force per centimeter is 10 gilberts, the total magnetomotive force would be 60 gilberts. The magnetomotive force per centimeter is called the magnetic force or the magnetizing force.

Units of Flux.

Previously when we were discussing magnetic flux we simply referred to the number of lines of flux. However, there is a term used for this purpose and it is the max-

well. One line of flux is equal to one maxwell. If you have a hundred flux lines, then the strength of the flux is 100 maxwells. Another unit is the kilomaxwell, which is equal to 1000 maxwells.

Another term that you will encounter is flux density. The flux density tells you how many maxwells or lines of flux pass through a given area. Flux density could be expressed in terms of maxwells-per-square-inch, or it could be expressed in terms of maxwells-per-square centimeter. A flux density of 1 maxwell or one line per square centimeter is known as a gauss. Thus if we say that the flux density is 100 gausses, we mean that there are 100 lines for each square centimeter of a cross-sectional area. If you had a magnet that was 3 × 5 centimeters, the total cross-section of the area would be 15 square centimeters. If the flux density is 100 gausses, then the total number of lines flowing would be 15 times one hundred or 1500 maxwells.

Units of Reluctance.

There is no unit of reluctance. Engineers and technicians are more concerned with the permeability of a material, which you might say is the opposite of reluctance. It is the ability of the material to conduct magnetic flux. It is similar to conductivity in an electric circuit, which is the ability of the material to conduct an electric current.

There is no unit of permeability. The permeability of magnetic materials is rated according to how much better the material conducts magnetic flux than air does. The permeability of air and all other non-magnetic materials is given the numerical value of 1. If the permeability of a magnetic material is 2, a magnetomotive force applied to it will produce twice as many flux lines as the same force applied to air. If we say the permeability of a certain magnetic material is 100, we mean that if the magnetomotive force applied to this material was applied to air, and it produced one line or one maxwell in air, then it would produce 100 flux lines or 100 maxwells in the material.

MAGNETIC SATURATION

One very important thing you should know about magnetic circuits is that they can be saturated. This means that they reach a point where all the possible lines of force exist, and increasing the magnetomotive force applied to the circuit will not produce any further increase in flux. Now let's see how this can happen.

A magnetic material such as iron is actually made up of millions of small molecules. A molecule is a tiny particle made up of a combination of two or more atoms. Each of these molecules is actually a small permanent magnet having a north pole and a south pole. When there is no magnetomotive force applied to the material, the molecules are arranged in a helter-skelter fashion as shown in A of Fig. 1. You will notice that the magnets in this material are pointing in all directions; there is no general organization so that all the north poles point in one direction and all the south poles point in another.

Let's see what happens if we apply a magnetomotive force to this material. This can be done by winding a

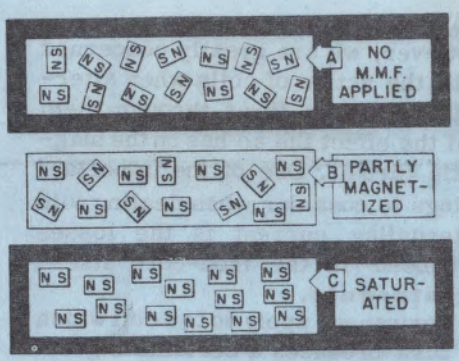


Fig. 1. How the molecules in a material line up as magnetomotive force is applied. Each molecule is like a tiny magnet.

coil around the material and passing a current through the coil. If the current is strong enough to partly magnetize the material, some of the molecules will line up as shown in Fig. 1B. Notice in this figure that there is a general tendency for the north poles to point towards the left and the south poles to point to the right. However, there are a number of molecules that do not follow this general pattern. Some of them are still not lined up.

If we increase the current flowing through the coil or if we increase the magnetomotive force by keeping the current constant and putting more turns on the coil, we will eventually reach a point where all of the molecules are aligned as in C of Fig. 1. Here all the north poles point to the left and all the south poles point to the right. When this situation exists, we say that the material is saturated. This means that any further increase in the magnetomotive force will not produce any further increase in flux. You can see why this is so--all the molecules are already aligned; therefore, it would be impossible to line any more of them up and get more flux. Thus, there would be no point in increasing the magnetomotive force. As a matter of fact, saturation is a condition to be avoided in most cases and if the current is increased beyond the amount needed to align all the molecules, some very undesirable results may occur.

Saturation is sometimes referred to simply as saturation; other times it is referred to as "core saturation" because the magnetic material is usually the core of some device. The magnet may be used as the core of a transformer or a choke. Only magnetic materials can be saturated; an air core cannot be saturated.

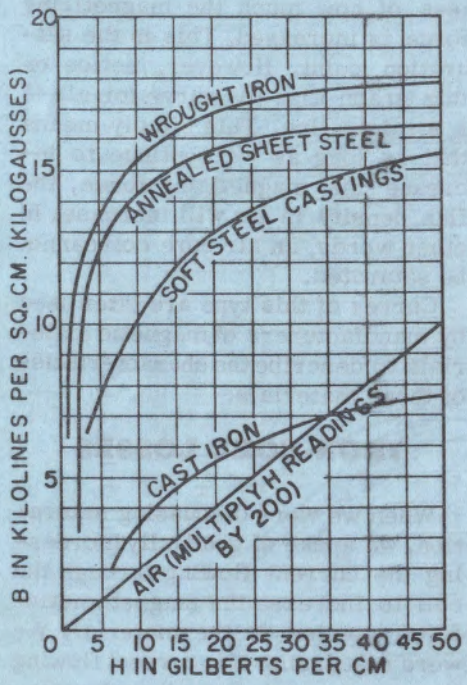


Fig. 2. B-H curves for different magnetic materials.

B-H Curves.

The characteristics of a magnetic material are often represented in the form of a curve called a B-H curve. B-H curves for several different materials are shown in Fig. 2. These curves show the flux density that can be obtained with a given magnetizing force. Notice that as the magnetizing force starts to increase from zero at the left of the graph, the flux density increases quite rapidly at first, then a point is reached where the curve starts to flatten out and it takes a substantial increase in magnetizing force to get even a small increase in flux density. Eventually a point is reached at which the flux density increases no further regardless of how much the magnetizing force is increased. This is the saturation point. However, notice on this graph that the curve for air is a straight line. This simply means that as long as we continue to increase the magnetizing force, the flux density in air will increase. In other words, an air core coil cannot be saturated.

Curves of this type are often used by manufacturers of magnetic materials to describe the characteristics of these materials.

IRON-CORE LOSSES

When we were discussing saturation, we spoke of gradually increasing the current flowing through the coil to increase the magnetomotive force applied to the material. We were discussing a dc current flowing through the coil. Even though we increased the current to show the effects of saturation, the current was still flowing in the same direction. However, we are greatly concerned with the action of coils when alternating current flows through them and the effect the ac has on the magnetic circuit. One of the important things to consider when dealing with alternating current is the losses produced in the iron-core itself.

Hysteresis.

Suppose we apply dc to a coil which in turn produces a certain magnetizing force. As the magnetizing force increases, the flux density increases, as shown by the curve A in Fig. 3, following a curve such as the B-H curves shown in Fig. 2. At zero, the material is not magnetized, and as we increase the magnetizing force, the flux density increases. Now suppose we increase the force only up to point 1 in Fig. 3, then we decide that we will not increase the current any further, but instead

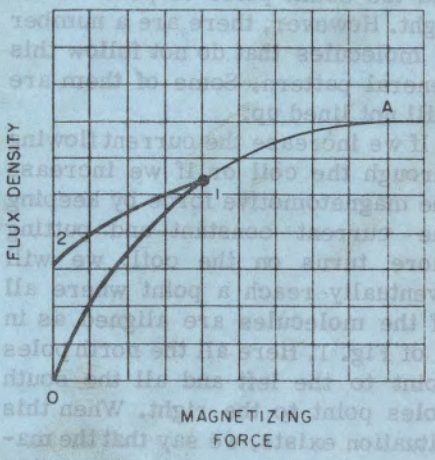


Fig. 3. Curve showing hysteresis loss in a magnetic material. If there were no loss, the curve 1-2 would coincide with the curve 0-1.

gradually decrease the current flowing through the coil, thus reducing the magnetizing force. As the magnetizing force is reduced, the flux density will decrease. However, instead of dropping back down to zero, it will follow the curve shown between points 1 and 2. At point 2, the magnetizing force has been removed entirely, but there is still a certain amount of flux. To get rid of this flux, we must actually reverse the current flowing through the coil. The power that must be applied to bring the flux density back to zero represents a loss due to the inertia of the magnetic circuit. This loss is called the hysteresis loss, pronounced hiss-ter-E-sis.

Any iron-core device operated from ac will waste part of the power applied to it in this way. There is no way that we can eliminate the hysteresis loss altogether, but the amount of power lost will depend upon the material used. By the proper choices of material, the loss can be kept to a minimum. For example, hard steel retains its magnetism and therefore the hysteresis loss in a material of this type would be quite high. On the other hand, soft iron and silicon steel retain very little of the magnetism so the hysteresis loss in the material of this type is much less than in hard steel. For this reason, the iron cores used in most transformers and chokes are made of silicon steel.

Eddy Current Losses.

Another loss that occurs in all iron-core devices is known as eddy current loss.

You will remember that when a varying current flows through a coil, a varying flux is produced in the coil.

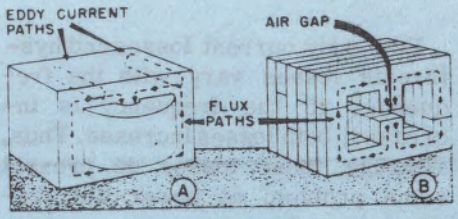


Fig. 4. If the core of a transformer is solid as at A, there are many eddy current paths in it; these can be reduced by making a laminated core as at B.

This flux will cut the turns of the coil and induce a voltage in it. The flux also cuts the turns of any nearby coil and induces a voltage in it, and if the circuit to this coil is complete, this induced voltage will cause a current to flow through it. If a transformer is made like the one shown in Fig. 4A, there are actually many paths in the core. Each path acts like a single-turn coil. We have shown two of these paths where a voltage can be induced which will result in a current flowing. These currents are called eddy currents and represent a loss.

The eddy current loss in a transformer core can be kept at a minimum by making the core out of thin sheets of magnetic material called laminations. The sheets are insulated from each other by a coating of shellac or some other non-conductive material. The sheets are then stacked as shown in Fig. 4B.

Eddy current losses cannot be completely eliminated because even though the core is made of thin sheets, there are still some complete paths present that act like single shorted turns. However, making the core of thin laminations reduces the eddy current losses to a low value.

Both eddy current losses and hysteresis losses vary with the frequency. If the frequency is increased, both losses increase. Thus, although these losses do present some problem at power-line frequencies, they present an even greater problem at audio frequencies, which may extend as high as 15,000 cycles or more. These losses also explain why even laminated iron-core transformers are of no value at radio frequencies. The losses become so high that all of the energy put into the primary of the transformer would be converted into heat due to the eddy current and hysteresis losses. At radio frequencies, magnetic cores are made of finely ground powdered iron mixed with a binder to hold the particles together and insulate them from each other.

Flux Leakage Losses.

Unfortunately not all the flux produced by the magnetomotive force applied to a magnetic circuit will flow through the iron core of a device such as a transformer. Part of the flux will escape and travel through the air surrounding the core. This flux serves no useful purpose since it leaks out of the core and these flux lines do not cut the turns of the secondary winding. This loss is referred to as flux leakage loss.

In a device such as a transformer, if the magnetic material used in the core approaches the saturation point, the flux leakage losses become quite high. Therefore, to keep this type of loss as low as possible, transformers are usually designed to operate well below the saturation point. However, even then it is impossible to eliminate this loss completely, because a certain amount of the flux produced by the primary will travel in a path other than through the core.

Flux leakage is important not only because it represents a loss in the transformer, but also because the escaping flux lines may cut through some nearby part and induce a voltage in it. Thus energy in the transformer can be unintentionally fed into some other part. The amount of energy fed back may be high enough to upset the performance of the equipment.

Flux leakage can also present a problem in television receivers. Flux leaking from a transformer can deflect the electron beam in a picture tube and cause distortion in the picture. In color TV receivers flux leakage can actually cause the color picture to break up into three separate pictures of different colors or cause color fringing where objects are outlined in one or more colors.

In designing electronic equipment using transformers, engineers must consider the possibility of these undesired effects and try to keep transformer leakage fields away from the picture tube in TV receivers or other parts in the electronic equipment that could pick up interference from the field. In equipment where several transformers are used, they try to place the transformers so that there will be a minimum of interaction between them.

SUMMARY

In this section, you reviewed the facts you previously learned about magnetic circuits. You also learned some new terms. A unit of magneto-

motive force that you will encounter is the gilbert and a unit of flux is the maxwell. You learned that the magnetomotive force is the force supplied throughout the entire magnetic circuit. Sometimes the force is expressed in terms of the magnetomotive force per unit length and is called the magnetizing force.

The amount of flux produced is sometimes expressed in terms of so many lines of maxwells for a given area. If the unit of cross-section area used is the centimeter, and you have 1 maxwell per square centimeter, we say the flux density is 1 gauss.

It is important for you to remember that a magnetic material can be saturated and that when the saturation point is reached, increasing the magnetomotive force will result in no further increase in flux.

The losses encountered in iron cores are important. The three most important losses are hysteresis loss, eddy current loss, and flux leakage loss. All these losses represent some energy that is being put into the primary of the transformer for which we get nothing out of the secondary. In the next section we will study transformers and you'll see the importance of these losses.

SELF-TEST QUESTIONS

(a) What is the gilbert?
(b) What is the unit of magnetic flux?
(c) What is meant by flux density?
(d) If the cross section area of a magnet is ten square centimeters and the flux density is ten gausses, what will the total number of flux lines flowing be?
(e) What is meant by magnetic saturation?
(f) Is magnetic saturation a desirable condition?
(g) How strong a magnetomotive force is required to produce saturation in air?
(h) What is a hysteresis loss?
(i) What are eddy current losses?
(j) How are hysteresis losses kept at a minimum?
(k) How are eddy current losses kept to a minimum?
(l) What are flux leakage losses?

Iron-Core Power Transformers

The ability of a varying magnetic field to induce a voltage in any conductor with which it links makes it possible to transfer power from one circuit to another without direct wiring connections. The device used for this purpose is called a transformer. In its simplest form a transformer is nothing other than two separate coils of wire wound on a common core or wound in such a way that the coils of wire are placed near each other so that the magnetic lines produced by one will cut the other.

A power transformer is wound on an iron-core. The iron-core is usually shaped like the core shown in Fig. 5A. The coils are wound on the center leg of the core as shown in Fig. 5B, one inside the other. The schematic symbol used to identify an iron-core transformer is shown in Fig. 5C.

No turns = $\frac{7.V}{lw}$

(for building transfm)

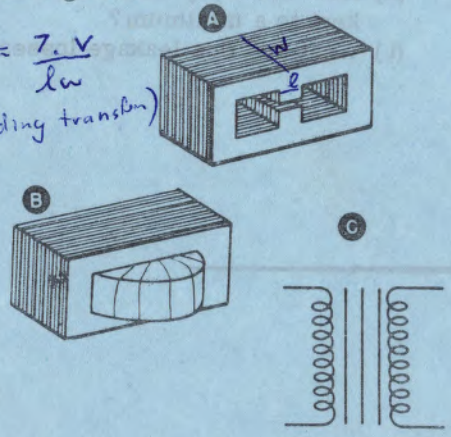


Fig. 5. The core of a power transformer is shown at A. The coils are wound on the center leg as at B. The schematic symbol for an iron-core transformer is shown at C.

Transformers are extremely important to the electronics technician, so let's learn more about them.

POWER LOSSES

In the preceding section of this lesson you learned about some of the losses that take place in magnetic cores. These losses, which are the hysteresis, eddy current, and flux leakage losses, are called "core" losses because they are characteristic of the magnetic core which is used in the transformer. However, there are also other losses in transformers.

The coils making up the transformer are wound of copper wire. Copper has a very low resistance, but nevertheless it does have some, so the current flowing through the copper wire will encounter opposition. This means power will be lost or used in forcing the current through the coil.

You know that the power is equal to voltage multiplied by the current; in other words:

$$P = E \times I$$

But from Ohm's Law we know that:

$$E = I \times R$$

Therefore, in the power formula we can substitute $I \times R$ for E, and get

$$P = I \times R \times I$$

which is usually written in the form

$$P = I^2R$$

The power lost as a result of current flowing through copper wire in a transformer will be equal to the current squared times the resistance of the wire. This loss is usually referred to as the "I squared R" loss.

Thus, in a transformer we have two groups of losses: the core losses and the copper losses. These losses appear in the form of heat. When a transformer is put into operation, it starts to heat up. The transformer will continue to get hotter and hotter until eventually a state of balance is reached where further heat generated by the transformer can be carried away by the air surrounding the transformer and by the metal chassis on which the transformer is mounted. When this balance is reached, the temperature of the transformer will stop rising, and the transformer will not get any hotter.

The amount of heat that a transformer can dissipate in this way depends upon its size. Since a large transformer will have a much greater air circulation and will be mounted on a larger area of the chassis, it can get rid of more heat than a small transformer. Therefore a large transformer is capable of handling a larger amount of power than a small transformer. As a matter of fact, the size of the transformer is usually a pretty good indication of the amount of power that it can handle safely. After you have worked on electronic equipment for a while, you'll learn to recognize from the size of a transformer approximately how much power it can handle.

Transformers can be overloaded if too much power is taken from them. When a transformer begins to overheat it is an indication that it is being overloaded. Usually when a transformer is overheated in this way you will notice a dark colored sealing compound or wax leaking out of the transformer, and often you can smell the varnish and insulation burning.

An overload of this type may be due to a defect in the transformer itself or it may be due to a defect somewhere in the equipment that is pulling excessive current from the transformer. If the transformer itself is defective, the trouble is usually that two or more turns of the transformer have touched each other so that a short circuit exists and current can simply flow around inside the transformer. When this happens there is nothing you can do except replace the transformer. However, if the defect is in the equipment rather than the transformer, and if you find it and eliminate the defect before operating the equipment any more, the chances are that the transformer will once again give satisfactory service.

If the transformer is operated with an overload, it will eventually get so hot that the insulation on the copper wire and on the terminal used to insulate one winding of the transformer from another will become overheated. Usually paper is used to insulate the various windings on a transformer. If this paper becomes too hot, it becomes charred so that it is no longer a good insulator, and the windings on the transformer will

short together. When this happens, the transformer is no longer usable because it will draw more and more current and it will get hotter and hotter and eventually it will blow a fuse or the copper wire on one of the windings will melt so that the winding opens.

Transformers are designed to operate on a specific frequency. In other words, a transformer designed to operate on a 50-cycle power line will operate best only on a power line of that frequency. If you operate a 50-cycle power transformer on a 25-cycle power line or accidentally plug it into a dc power line, the transformer will burn out. A 50-cycle transformer cannot be operated on a 25-cycle power line. No transformer can be operated from dc. A 25-cycle transformer will operate on a 50-cycle power line, but 25-cycle transformers are much larger and much more costly to manufacture than 50-cycle transformers, and therefore it would be uneconomical to design a transformer for 25-cycle power and then use it on a 50-cycle power line.

In spite of the losses we have discussed, a transformer is one of the most efficient devices you will ever find. Large transformers such as those used by the power company achieve a very high efficiency, usually from 98% to 99%. Smaller transformers such as you will find in electronic equipment usually operate at an efficiency of somewhere between 95% and 98%. As far as the technician is concerned, this high efficiency means that in many cases you can ignore the transformer losses. You can consider the power output of the transformer as being equal to the power input; the difference will be only a small percent of the total power, and in evaluating the performance of the transformer, very little error will be introduced.

TURNS RATIO

The turns ratio of a transformer is the ratio of the number of turns on one winding of the transformer to the number of turns on the other winding. For convenience we usually identify the two windings on a transformer as the primary winding and the secondary winding or, more simply, as the primary and the secondary. The primary is the winding to which we apply the input power. The secondary winding is the winding from which we take power. If the primary winding of the transformer has 500 turns, and the secondary winding has 100 turns, we say that the transformer has a turns ratio of 5 to 1. This is often written 5:1. If the primary of the transformer has 100 turns, and the secondary 500 turns, then we say that the transformer has a turns ratio of 1 to 5 (1:5).

The ratio of the secondary voltage to the primary voltage will depend upon the turns ratio. If the secondary winding has five times as many turns as the primary, we can expect to get five times the voltage from the secondary that we put into the primary. Similarly, if the secondary has only half as many turns as the primary, then we can expect to get half the voltage across the secondary that we put into the primary. If we get more voltage out of the secondary than we put into the primary, the transformer is called

7 turns/volt/1" core.

a "step-up" transformer, and if we get a lower voltage out of the secondary than we put into the primary, then the transformer is called a "step-down" transformer.

In expressing the turns ratio of a transformer, manufacturers and technicians do not always give it as the ratio of the primary turns to the secondary turns. If a transformer has 100 turns on the primary and 200 turns on the secondary, the turns ratio is 1:2. However, sometimes this turns ratio is given as 2:1, step-up. This tells you the transformer is a step-up transformer which means there are more turns on the secondary than on the primary and the secondary has twice as many turns as the primary.

Power Consumption.

One of the things that makes a transformer so useful is that it is basically a self-regulating device. By this we mean it takes no more power from the power line to which it is connected than is needed to supply the power demanded from the secondary. In other words, if we connect a load across the transformer secondary and this load consumes 50 watts, then the power drawn from the power line by the primary will be 50 watts. Similarly, if we connect a 100-watt load across the secondary, then the power drawn from the power line by the primary will be approximately 100 watts. The primary will draw approximately the power required in order to furnish the demands of the secondary. We say approximately, because there are losses in the transformer itself, and the primary will draw the power needed to supply the secondary power plus the power needed to supply the losses within the transformer itself.

Consider what happens when the primary of the transformer is connected across the power line, but there is no load connected across the secondary. Under these circumstances, the secondary power is zero. Therefore, the primary does not have to supply any power to the secondary, and the power it will consume for this purpose will also be zero. The only power that the primary will consume from the power line will be the power to make up the core losses and a very small copper loss. Thus, when the primary of a transformer is connected across the voltage source and there is no load connected to the secondary, the transformer draws very little power from the voltage source. Under these circumstances, the transformer is very inefficient because all the power it is consuming is being wasted. However, as we load the secondary, these losses remain almost constant and as the secondary begins to use power, the primary power increases until when the transformer is being operated at its rated power, its efficiency reaches a very high value.

Because the primary power depends upon the secondary power, the actual current that will flow through the primary of a transformer will depend upon the load connected to the secondary. Ignoring the core and copper losses, if we have a 10 to 1 step-down transformer connected across a 100-volt power line, the voltage available at the secondary will be 10 volts. The turns ratio determines the ratio of the primary to secondary voltage. The ratio of the

To calculate eff

$P = \frac{1}{E \text{ per rev}} \times \frac{3600}{\text{Rev}} \text{ meter const.}$ (on an open circuited secon

current flowing in the primary to the current flowing in the secondary also depends on the turns ratio, but it works in the opposite way. If we connect a load across the secondary that draws a current of 1 amp, then the power taken from the secondary will be 10 volts times 1 amp, which equals 10 watts. To supply 10 watts, the primary, since the voltage across it is 100 volts, needs only 1/10 of an amp and therefore this is the current that it will draw from the power line. If we increase the load across the secondary and pull 100 watts from the secondary, then the current flowing in the secondary must be 10 amps, because with a voltage of 10 volts, it will take a current of 10 amps to supply 100 watts. Under these circumstances, the primary again will pull the power needed from the power line to supply this 100 watts. This means that the primary current will be 1 amp.

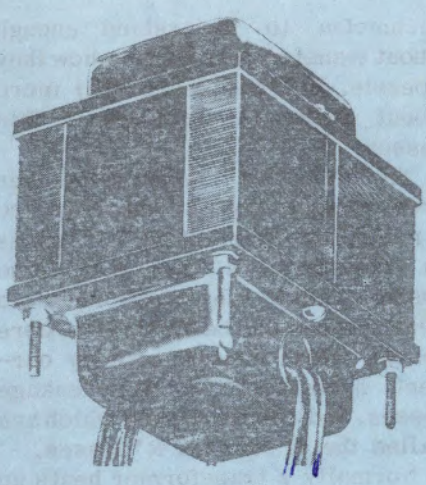
Now notice what our situation is. Here we have a step-down transformer with a 10-to-1 turns ratio. This transformer steps the voltage from 100 volts down to 10 volts. However, the current acts in the opposite way. The secondary current is higher than the primary current. The secondary current will actually be 10 times the primary current if we ignore the transformer losses. Therefore in a step-down transformer, the current is stepped up and similarly in a step-up transformer where the voltage is stepped up, the current is stepped down.

Since the current drawn from the primary will vary as the loading on the secondary of the transformer varies, this means that the impedance of the primary winding must vary. If the impedance of the primary winding remained constant, then the current flowing through the transformer primary would be constant for any given primary voltage. However, since the current does vary, then the impedance must vary. This it does, in fact, and the actual impedance of the primary depends upon the impedance connected across the secondary. This is caused by the fact that when the impedance across the secondary varies, the current as well as the power demanded from the secondary will vary. The primary current and the impedance will also vary in turn.

TYPICAL POWER TRANSFORMERS

Many pieces of electronic equipment that you will service will use power transformers. Power transformers serve a number of useful purposes. First, by using a power transformer it is possible to have available a number of different operating voltages other than the single voltage available directly from the power line. Furthermore, the power transformer isolates the equipment from the power line. This is a big advantage because one side of most power lines is grounded. If you accidentally come in contact with any grounded object and some of the circuits of the electronic equipment or the metal chassis of the equipment at the same time, it is possible to get a severe shock from electronic equipment that does not use a power transformer.

The power transformer found in modern electronic equipment has a primary winding and one or more



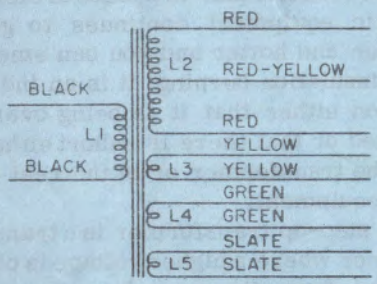


Fig. 6. A typical power transformer and its schematic symbol.

secondary windings. A photo of a typical power transformer and the schematic symbol used to represent it are shown in Fig. 6.

The winding marked L1 is the primary winding. It is usually operated from a 240-volt, ac power line.

The secondary winding marked L2 is a high-voltage secondary. Notice that this winding is center tapped. This type of winding is used with a full-wave rectifier.

A full-wave rectifier is a rectifier that rectifies both halves of each cycle. This winding is a stepup winding and is used to provide a voltage somewhat higher than that available from the power line to operate the plates of the various tubes in electronic equipment. Voltages of 250 to 350 volts are found in most circuits of modern radio and TV receivers; much higher voltages are found in transmitting equipment and in other pieces of industrial electronic equipment.

The winding marked L3 is a step-down winding. This winding is used to provide the filament voltage to operate the filament of the rectifier tube, which is used to change the ac to pulsating dc. The windings marked L4 and L5 are also low-voltage windings. These windings are used to provide the heater voltage required by the various tubes in the equipment. Some transformers have two low-voltage secondary windings like L4 and L5 on this transformer, but others have only one low-voltage secondary to heat the various tubes.

Notice that the number of turns used in the schematic symbol gives some indication of whether the windings are step-up or step-down windings. L2 has more turns than L1, and here you can expect the voltage from L2 to be higher than the primary voltage applied to L1. The windings L3, L4, and L5 have fewer turns than L1, indicating that their voltage is less than that of the primary winding. However, the schematic is not intended to show the exact number of turns or the turns ratio.

The colors have been labeled on the various leads from this transformer. This is a standard color

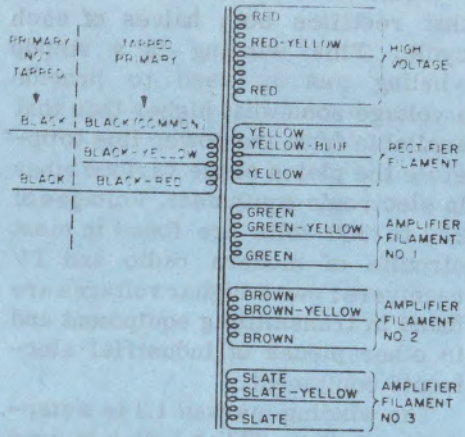


Fig. 7. A standard color code for power transformers.

code used to identify transformer leads. The complete color code is shown in Fig. 7. However, do not expect all transformers to follow this standard color code. Some manufacturers use a color code of their own. Therefore, even when you are using the color code to identify the leads on a transformer, you should pay some attention to how the transformer is connected into the circuit, the size of the various wires, etc., to be sure that the manufacturer has followed the standard code.

SUMMARY

We have not tried to cover all the facts about iron-core power transformers in this section of this lesson. Transformers are a subject all by themselves. Some engineers spend their whole careers designing different types of transformers. However, the information covered in this section will enable you as a technician to understand enough about transformers to know how they operate. You will learn still more about audio transformers in this lesson.

The important thing to remember from this section is that there are a number of different types of losses in transformers and that these losses cause the transformer to heat. Losses can be divided into core losses which consist of eddy current, hysteresis, and flux leakage losses, and copper losses which are called the "I squared R" losses.

Normally a transformer heats up as it is used, until it reaches a point at which it does not get any hotter. If the transformer in a piece of electronic equipment continues to get hotter and hotter and you can smell the insulation burning, it is an indication either that it is being overloaded or that there is a short either in the transformer or in the rest of the equipment.

A step-up transformer is a transformer where a higher voltage is obtained from the secondary than is put into the primary, and a step-down transformer is a transformer where a lower voltage is obtained from the secondary than is put into the primary. The power output from the secondary of a transformer is approximately equal to the power input of the primary. Thus in a step-up transformer where the secondary voltage is higher than the primary voltage, the primary current must be higher than the secondary current. Conversely, in a step-down transformer where the secondary voltage is lower than the primary voltage, the primary current will be lower than the secondary current.

Power transformers used in electronic equipment usually have several secondary windings. One secondary winding is used to provide the high voltage needed to operate the plates of the various tubes. The other secondary windings usually supply the heater voltage required by the rectifier and the other tubes in the equipment. Most transformers use a standard color code which can be used to identify the various transformer leads.

SELF-TEST QUESTIONS

(m) What is a transformer?

(n) What are the two types of losses encountered in a transformer?

(o) What happens to the power lost in a transformer?

(p) Is a transformer generally considered an efficient device?

(q) Can a power transformer designed for operation on a 50 cycle power line be used on a 25-cycle power line?

(r) What do we mean by a step-up transformer?

(s) If you have a step-down power transformer with a turns ratio of 3:1, and the current being drawn from the secondary is 3 amps, what will the primary current be?

(t) The load connected across the secondary of a power transformer consumes 230 watts. If the primary of the transformer is operated from a 230-volt power line, what will the primary current be if we consider the transformer efficiency as 100%?

(u) A power transformer has a turns ratio of 2:1. The transformer is operated from a 240-volt power line, and the device connected to the secondary winding draws a current of 4 amps. What will the primary current be?

Transformers for Specific Application

As an electronics technician, there are a number of different types of transformers that you will encounter. We are not going to try to cover all of them here, but we will discuss a few of the more common types. The material in this section of the lesson is used simply to introduce you to these special types. Later we will go into the transformers in more detail when we study the applications in which they are used.

AUDIO TRANSFORMERS

In the early days of radio, audio transformers were used as coupling devices between the various stages of the receiver. By using a step-up transformer, the strength of the audio signal could be increased in the transformer itself. This was a big help, because the tubes used in those days did not have a great deal of gain. However, modern tubes have high gain and audio transformers introduce frequency distortion, so they are no longer used with tubes for this purpose.

Impedance Matching.

You will remember that to transfer maximum power from a dc generator to a load, the load resistance must be equal to the generator resistance. In ac circuits, to transfer maximum power from a generator to a load, the load resistance must be equal to the generator impedance. To transfer maximum power from one stage in an amplifier to the following stage, the impedances must be matched. Transformers are frequently used for this purpose, particularly in transistorized equipment. For example, the output circuit of a transistor may have a much higher impedance than the input circuit of the following transistor. To transfer the power from the one transistor to the second one, an impedance-matching transformer is used.

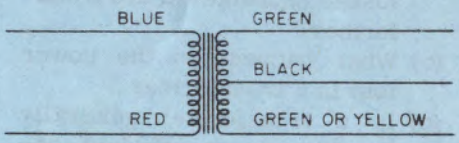


Fig. 8. An audio transformer with a tapped secondary.

Another application in which a transformer may be used is where a single tube or transistor is used to drive two tubes or two transistors. Then an audio transformer with a tapped secondary such as shown in Fig. 8 is used. With this type of transformer, the center tap winding is either connected to ground or used to supply bias to the stage. The two tubes or transistors are driven with signals of the opposite polarity. In other words, when the signal on the top green lead in Fig. 8 is swinging positive, the signal on the lower lead that is green or yellow will be swinging negative. Thus when

Max power transfer when Imps equal

the current in one of the stages is increasing it will be decreasing in the other and vice versa. This type of stage is called a push-pull stage and is frequently used in the output stage of high fidelity equipment in order to obtain a high power output with low distortion. We will cover this in detail later when you study tubes and transistors.

Another place where transformers are widely used in audio circuits is in the output between the last amplifier stage and the loudspeaker. The output impedance of the power output tube or the power output transistor is generally much higher than the speaker voice coil impedance. A transformer, which is called the output transformer, is used to match the output stage to the loudspeaker in order to transfer maximum power from the output stage to the speaker. A transformer of this type will have a step-down turns ratio in order to match the higher impedance of the output stage to the lower impedance of the speaker.

You saw in an earlier lesson that to transfer maximum dc power from a generator to a load, that the generator and load resistances had to be equal. Now let's see how a transformer can be used in an ac circuit to match the load impedance to the generator impedance, so that the generator will deliver maximum power to a load that has an impedance different from the generator impedance.

In Fig. 9, we have shown how the power supplied to the load by a generator that has a no load voltage of 100 volts and an internal impedance of 50 ohms varies as different load resistors are connected across it. You will notice that when the 50-ohm load is connected across the generator, we obtain 50 watts across the load. If the load impedance is reduced below this value, then the power transferred from the generator to the load drops off.

Similarly, if the load impedance is increased above 50 ohms, the power drops off.

With a 50-ohm load connected across the generator, the total circuit resistance is 100 ohms: the 50-ohm load, plus the 50-ohm generator impedance. The 100 volts generated will be divided with 50 volts being dropped in the generator and 50 volts in the load. The current flowing in the circuit will be 1 amp.

LOAD RESISTANCE IN OHMS	POWER IN WATTS
200	32
150	37.5
100	44.4
50	50
25	44.4

Fig. 9. Power supplied by a 100-volt generator with an internal impedance of 50 ohms for various values of load resistance.

If we remove the 50-ohm load resistor, and connect some other device in its place that will draw a current of 1-amp from the generator, then there will be 50 volts across this device and the power supplied to it will be 50 watts, which we know is the maximum power that can be taken from the generator. A transformer can be used for this purpose providing it has the proper turns ratio, and providing the correct load

$\frac{N_p}{N_s} = \sqrt{\frac{Z_p}{Z_s}}$

is connected across the secondary of the transformer.

The usual problem is to have the generator and the load and then have to select the transformer. Let's assume that we have a 2-ohm load resistor we want to connect across the generator and see how a transformer can be used to get 50 watts from the generator to the load.

We know that the maximum power that can be transferred from the generator to the load is 50 watts. Now let's find out what the voltage across the resistor and the current through the resistor must be in order to get 50 watts into the resistor. Remember the formula:

$$P = I^2 \times R$$

We know that P = 50 watts, and R = 2 ohms; therefore we can find the value of I^2 in this manner:

$$I^2 = 50 \div 2 = 25$$

This means that the current squared is equal to 25. We know that the square root of 25 is 5, because $5 \times 5 = 25$. Therefore the current that must flow through the resistor is 5 amps. In order to figure how much voltage we need to get a current of 5 amps to flow through a 2-ohm resistor, we use the formula: $E = I \times R$. This gives us 2×5, which equals 10 volts.

So far we have found that to get 50 watts into a 2-ohm load resistor, we must have a voltage of 10 volts across it. When we have 10 volts across the resistor, a current of 5 amperes will flow through it, and the power supplied to the resistor will be 50 watts. However, we still have the problem of getting the 10 volts across the resistor.

The transformer presents an easy method of doing this. We know that when we had maximum power transfer from the generator to the load, we had 50 volts across the load. However, in the problem we have set up, we want only 10 volts across the load. The way to satisfy both of these conditions is to connect a transformer across the generator as shown in Fig. 10. If we use a transformer with a turns ratio of 5 to 1, we will be able to satisfy these conditions.

You will remember that the transformer is a self-regulating device. The primary will take the power from the source needed to supply the power demanded by the secondary. Under these circumstances when the generator, transformer, and load are connected as shown in Fig. 10, the primary current that

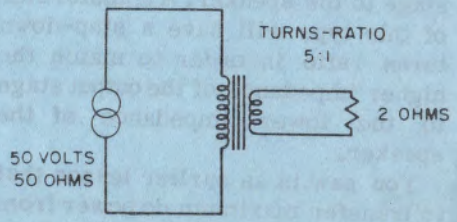


Fig. 10. A transformer used to match a 2-ohm resistor to a generator with an internal resistance of 50 ohms.

will flow will be 1 amp. This means that there will be 1 amp through the primary of the transformer, and therefore the power consumed by it will be 50 watts. The 50 volts applied to the primary will be stepped down by the transformer to give 10 volts across the secondary. With the 2-ohm load connected across the secondary, the secondary current will be 5 amps, and the power con-

sumed by the secondary will be 50 watts. Since the transformer is a step-down transformer, the current is stepped up. The primary current of 1 amp is stepped up to a current of 5 amps in the secondary.

Under these circumstances, as far as the generator is concerned, it works exactly as it would if a 50-ohm resistor were connected across it. The transformer has matched the two-ohm resistor to the generator. Technicians say that the generator "looks into" the load and it looks like a 50-ohm load connected across it. Because the transformer matches the load impedance to the generator to provide the generator with the impedance required to transfer maximum power from the generator to the load, the transformer is called an impedance-matching transformer.

Turns Ratio.

Notice the ratio of the two impedances we matched. The generator impedance was 50 ohms, the load 2 ohms. The ratio of these two impedances is 50 to 2 or 25 to 1. The turns ratio of the transformer, however, was 5 to 1. But 5 is the square root of 25. Thus the relationship between the impedances to be matched and the turns ratio of the transformer needed to match the impedance is:

$$\frac{N1}{N2} = \sqrt{\frac{Z1}{Z2}}$$

where Z1 is the generator impedance, Z2 the load impedance, N1 the number of turns on the primary of the transformer, and N2 the number of turns on the secondary. Thus, N1/N2 is the turns ratio.

AUTOTRANSFORMERS

The schematic of another type of transformer is shown in Fig. 11. As you can see from the schematic, this transformer consists of a single winding with a tap. It is called an autotransformer because it has only one winding. (Auto is the Greek word for "self".) In the transformer shown in Fig. 11A, the secondary voltage is higher than the primary voltage because there are more turns on the secondary than there are on the primary. In the transformer shown in Fig. 11B, the secondary voltage is lower than the primary voltage because the primary has more turns than the secondary.

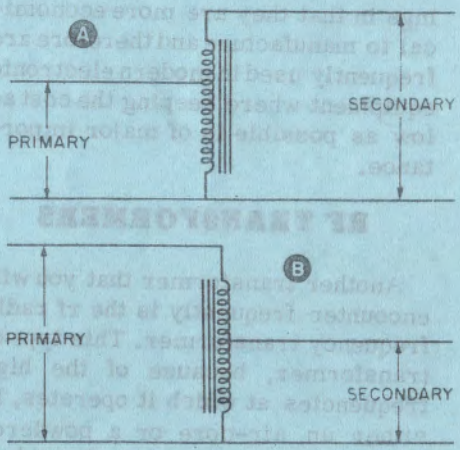


Fig. 11. Schematic of an autotransformer.

The autotransformer is different from a conventional transformer in that the primary and secondary windings are not insulated from each other. The voltage applied to the primary will set up a magnetic field, and this magnetic field will cut all the turns of the secondary, including

those which may be a part of the primary, and induce a voltage in them. This voltage will appear across the secondary terminals of the transformer and if we connect a load to these terminals, current will flow through the load.

Autotransformers have the disadvantage that the primary and secondary windings are not completely isolated from each other electrically. In other words, there is an electrical connection between the primary and secondary windings. As a matter of fact, one lead connects directly to both primary and secondary windings as you can see from the diagrams in Fig. 11. However, they have the advantage over the transformer with two separate windings in that they are more economical to manufacture and therefore are frequently used in modern electronic equipment where keeping the cost as low as possible is of major importance.

RF TRANSFORMERS

Another transformer that you will encounter frequently is the rf radio frequency transformer. This type of transformer, because of the high frequencies at which it operates, is either an air-core or a powdered iron-core transformer. A typical rf transformer designed for use at standard broadcast band frequencies is shown in Fig. 12.

RF transformers are used in the stages of a radio or TV receiver that are designed to amplify the received signal frequency. In other words, in the case of a broadcast band receiver, the signal is picked up and amplified by one or more rf stages before it is processed in any way. RF transformers are used between stages of this type.

In most cases, the secondary of the transformer, at least, is used in conjunction with a variable capacitor to form a resonant circuit. The rf transformer acts very much like the step-up transformer, because if the secondary is tuned to resonance, the circuit forms a

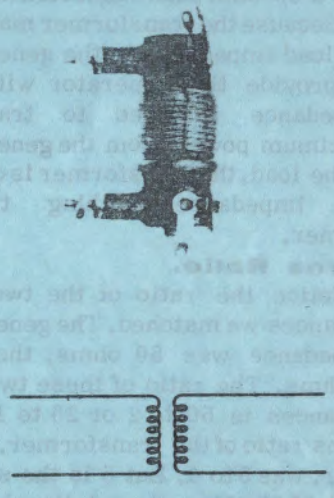


Fig. 12. A typical rf transformer and its schematic symbol.

series-resonant circuit and there will be a resonant voltage step-up across the secondary of the transformer. This situation exists even though the primary of the transformer may have the same number of turns as the secondary. Here the step-up in voltage is being obtained because of the action of the resonant circuit, rather than the action of the transformer.

In TV receivers where the rf stages must operate on a much higher frequency, an rf transformer may consist of only one or two turns of wire on the primary winding and the same number of turns on the secondary. If one winding of the transformer is tuned to resonance, it is usually tuned by stray circuit capacitances and capacitances in the tubes or transistors used in the stage rather than by a separate variable capacitor.

RF transformers are sometimes called rf coils, but are actually transformers. Their operation is similar to that of the iron-core transformers you studied earlier in this lesson.

I-F TRANSFORMERS

Modern radio and television receivers use what is called a superheterodyne circuit. In this type of circuit the incoming signal is fed to a stage called a mixer stage where it is mixed with a locally generated signal. The output of the mixer stage produces a new signal frequency which is called the intermediate frequency. We abbreviate this i-f and call the stages used to amplify this signal i-f stages. Between the various i-f stages we use transformers called i-f transformers.

A typical i-f transformer and its schematic diagram are illustrated in Fig. 13. The primary winding of the transformer and its capacitor form a parallel-resonant circuit, and the secondary winding and its capacitor form a series-resonant circuit. Both the primary and the secondary windings are tuned to the same frequency and usually the two windings have exactly the same number of turns on them. However, again because the secondary is a series-resonant circuit, there is a resonant voltage step-up and the voltage across the secondary winding will be higher than the voltage across the primary winding.

Even though the primary and secondary windings of an i-f transformer are tuned to resonance at a specific frequency, they are de-

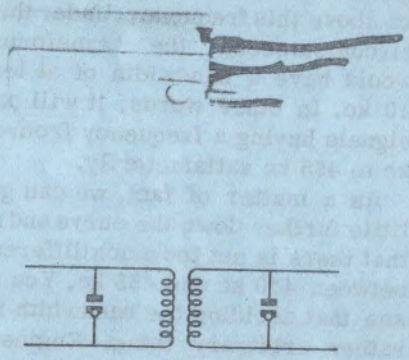


Fig. 13. A typical i-f transformer and the schematic symbol for it.

signed so that they have a certain bandwidth. By this we mean that instead of passing only one specific frequency, the transformer will pass a band of frequencies. The actual bandwidth depends upon the design of the transformer and the frequency at which it operates. The bandwidth of a transformer can be shown by means of a response curve such as shown in Fig. 14. Here you will see that the resonant frequency is 455 kc, but there is very little differ-

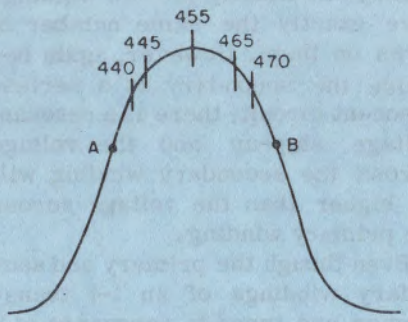


Fig. 14. An i-f transformer response curve.

ence in the response of the transformer either 10 kc below or 10 kc above this frequency. Under these circumstances, the transformer would have a bandwidth of at least 20 kc. In other words, it will pass signals having a frequency from 445 kc to 465 kc satisfactorily.

As a matter of fact, we can go a little further down the curve and see that there is not too much difference between 440 kc and 455 kc. You can see that deciding the bandwidth is a rather arbitrary thing. Engineers have set up as a standard the point where the response falls to .707 of the response at the resonant frequency. This is the half-power point you have already studied. The bandwidth of the i-f coil is the frequency between the .707 point on the low side of the curve and the .707 point on the high frequency side of the curve. These points have been marked A and B on the response curve shown in Fig. 14.

They are called the "3-db down" points. The abbreviation "db" means decibel. It is a means of expressing power ratio. The 3-db down points, A and B in Fig. 14, are within 3-db of the resonant frequency.

We do not expect you to understand the decibel at this time; we will go into it in more detail eventually. However, keep in mind the expression "3-db down", because this expression is frequently used by technicians and engineers. It is an idea that is somewhat difficult to grasp, but one of the first steps in seeing what is meant is becoming familiar with the term. Now that you have been introduced to it, the next time you will see it, it will not seem quite so strange to you.

When you look at Fig. 13 you might think that the primary and secondary windings are placed so far apart that there would be very little coupling between the two of them. However, there actually is considerable coupling between the two windings. The spacing of the transformer windings is adjusted to give exactly the desired amount of coupling. If the coils are placed too close together, then the curve shown in Fig. 14 tends to flatten out and have a dip in the center around a 455 kc point.

In TV i-f transformers, the coils are placed much closer together; in fact, often one is wound directly on top of the other. This is done in order to provide what is called very tight coupling and to spread out the response curve to pass a wide band of frequencies. You will see later that in television we must be able to pass a wide band of frequencies; otherwise, part of the picture information in black and white transmissions or part of the color information in color broadcasts will be lost.

TV i-f transformers do not have

a separate capacitor across the primary and secondary windings like the one shown in Fig. 13. There is enough capacity in the circuit and in the output and input in the various stages to provide the capacity required in order to bring the windings on the transformer to resonance.

SUMMARY

In this section of the lesson, you have been introduced to a number of new types of transformers.

You have learned that transformers are used between the audio stages in some pieces of equipment. Many of these transformers are step-up transformers so that the voltage across the secondary may be two or three times the voltage across the primary. However, in some high-power audio equipment, step-down transformers are used between audio stages. Transformers with tapped secondaries may be used when one tube must drive two tubes.

Transformers are used as impedance-matching devices. In order to get maximum power from a generator to a load, the load impedance must be equal to the generator impedance. This situation can be met by using a transformer with a suitable turns ratio to match the load impedance to the generator impedance so that the generator operates as if it were working into a load equal to its own internal impedance. Impedance-matching transformers are used between the output stage of a radio or TV receiver and the loudspeaker. Because these transformers are used at the output of the receiver they are usually called "output" transformers.

You have learned that the autotransformer is a single-winding transformer. Part of the transformer winding serves as both the primary and secondary. The autotransformer is frequently used to step up the line voltage if it is somewhat lower than normal.

We have also mentioned rf transformers. Although we did not go into a great deal of detail about them, you should recognize an rf transformer the next time you see one. An rf transformer has two windings, a primary and a secondary winding, and it operates in very much the same way as an iron-core transformer.

I-F transformers have both a tuned primary and a tuned secondary. The primary is a parallel-resonant circuit. The secondary is a series-resonant circuit. An i-f transformer has a certain bandwidth; this means that the transformer will pass frequencies above and below the frequency to which it is resonant. The bandwidth of a transformer is defined as the frequency difference between a point on the low side of the response curve and a point on the high side of the response curve at which the output from the transformer is .707 of the output at resonance. These points are called "3-db down" points.

SELF-TEST QUESTIONS

(v) Are step-up type audio transformers used in modern electronic equipment?

(w) What is the major use of audio transformers in electronic equipment?

(x) Why is it important that the

output stage in a radio receiver or a TV receiver be matched to the speaker voice coil?

(y) What type of audio transformer is used to drive a push-pull stage from a single driver stage?

(z) What must the turns ratio of an output transformer be to match a speaker with a 10-ohm voice coil to an output stage that has an output impedance of 1000 ohms?

(aa) What is an autotransformer?

(ab) Is an autotransformer a step-up transformer or is it a step-down transformer?

(ac) What is the disadvantage of an autotransformer?

(ad) What is an rf transformer?

(ae) What type of core would you expect to find in an rf transformer?

(af) In a typical i-f transformer used in a broadcast receiver, the primary and secondary windings will have the same number of turns. However, in spite of this, the voltage across the secondary winding will be higher than the voltage across the primary winding of the transformer. Why is this so?

Voltage change with load is called Regulation

Iron-Core Chokes

A choke is a coil used to purposely introduce a high reactance in a circuit. An iron-core choke is a coil wound on an iron core. A typical iron-core choke and the schematic symbol used to represent it are shown in Fig. 15.

Iron-core chokes are sometimes found in audio equipment, but their most important use is in power supplies. Here they are used in conjunction with capacitors to smooth the pulsating dc from the output of the rectifier. Chokes that are used for this purpose are called filter chokes or smoothing chokes.

PHYSICAL AND ELECTRICAL CHARACTERISTICS

It is sometimes difficult to distinguish an iron-core choke from a small power transformer. However, an iron-core choke usually has only two leads, whereas a power transformer has more than two leads. However, some iron-core chokes have a tapped winding. This type of choke has three leads and is very rare; most chokes have only two leads and can be distinguished easily from a transformer by this characteristic.

The core on which an iron-core choke is wound is similar to a transformer core. Thin sheets of laminated silicon steel are used in constructing the core. A frame is generally provided around the core and this frame serves the dual purpose of holding the laminations of the core together tightly and also in providing a convenient method of mounting the choke. You can see the frame in Fig. 15.

The core of an iron-core choke is made of silicon steel, which keeps the hysteresis losses in the choke as low as possible. The core is laminated to keep the eddy current losses low. The pulsating dc that is fed to a filter choke is actually a mixture of ac and dc. The ac has exactly the same effect in the choke as it has in a transformer, so both hysteresis and eddy current losses are present.

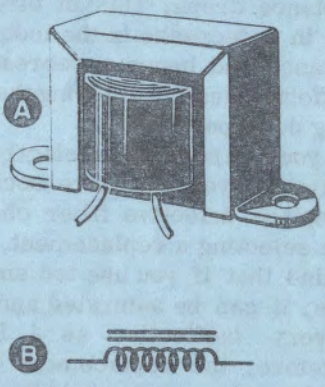


Fig. 15. A typical iron-core choke and its schematic symbol.

A choke used in a power supply usually has a fairly high inductance. Inductances from about 1 henry up to 30 or 40 henrys are quite common.

The size of wire chosen for winding a choke is determined by the current that will flow through the choke.

When an iron-core choke is used as the filter choke in the power supply, there is usually a high dc current flowing through it; superimposed on this dc is ac. The wire with which the choke coil is wound must be large enough to accommodate this current without overheating.

The current that flows through the choke coil will govern the size of core required. Saturation, which you have already studied, must be avoided in chokes. It can be avoided only by using an iron-core large enough to handle the magnetic field developed by the coil without reaching the saturation point.

If a choke becomes saturated, its inductance drops. This in turn results in a decrease in the inductive reactance and hence a decrease in its effectiveness in filtering the pulsating dc to pure dc.

In your career as an electronics technician, you will have occasion to replace defective filter chokes. When selecting a replacement, keep in mind that if you use too small a choke, it can be saturated and thus be very ineffective as a filter. Therefore, the replacement choke should be of approximately the same physical size as the original choke and the wire used to wind the choke should be at least as large as the wire used to wind the original choke. Technicians usually do not concern themselves with the wire size because manufacturers rate their chokes giving the inductance and the current that the choke is designed to handle. Thus, a choke rated at 8 henrys, 250-ma, is a choke that will have an inductance of 8 henrys when a dc current of 250 milliamperes is flowing through it. If the current flowing through the choke is higher than 250 milliamperes, the core will approach the saturation point, and the inductance will drop. If the current flowing through the choke is less than 250 milliamperes, the inductance of the choke will be somewhat higher than 8 henrys. This will not cause any trouble; the equipment will work as well as ever. If the current flowing through the choke exceeds the 250-ma current rating substantially, the chances are that the choke will overheat and may eventually get so hot that it will burn out.

HOW CHOKES ARE USED

We mentioned that chokes are used along with capacitors in power supplies to help smooth the pulsating dc at the output of the rectifier to pure dc at the output of the filter network. A typical circuit showing how a choke and a capacitor may be used is shown in Fig. 16. To see how the combination acts to filter the pulsating dc, first consider that the pulsating dc at the input actually consists of two components, ac superimposed on dc. To understand the action of the choke and capacitor, we can study their action on the two components separately.

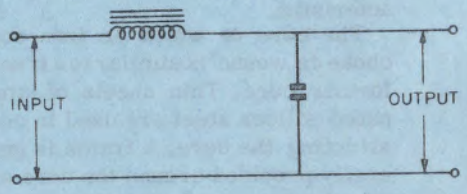


Fig. 16. A filter network made up of a choke and a capacitor.

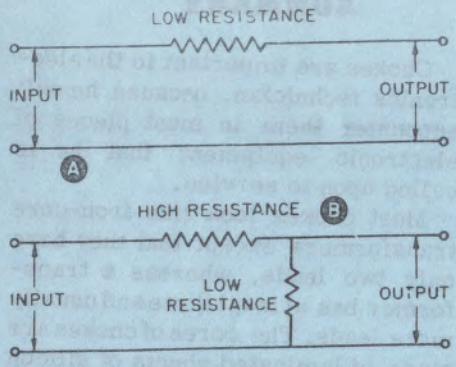


Fig. 17. The effect of the filter circuit for a dc component is shown at A, and for an ac component at B.

You know that a choke offers little or no opposition to the flow of dc through it. The only opposition the choke will offer to the flow of dc will be due to the resistance of the wire used to wind the coil. Since this is normally quite low, the dc can flow from the input through the choke coil to the output without any difficulty. The capacitor is charged by the dc, but once it is charged, it will not draw additional dc through the choke. Between the input and output circuits, we actually have a very simple circuit like the one shown in Fig. 17A insofar as the dc is concerned. Notice that we have only a low resistance in the circuit. The capacitor is not shown, and it can be completely ignored insofar as the dc flowing in the circuit is concerned.

The action of the choke and capacitor to the ac component is completely different. The choke, since it has inductance, has inductive reactance and is usually selected so that the inductive reactance will be quite high. The capacitor on the other hand is selected with a low capacitive reactance. Thus, insofar as the ac is concerned, we have a circuit like the one shown in Fig. 17B. Here we have a high resistance taking the place of the choke and a low resistance taking the place of the capacitor. Now these two "resistors" act like a voltage divider and most of the voltage will be dropped across the high resistance and very little will appear across the low resistance in the output. If the reactance of the choke is ten times the reactance of the capacitor, the ac component at the output would be approximately 1/10 the ac at the input.

If further filtering is needed to smooth the pulsating dc more than it can be smoothed by a single choke and capacitor, two chokes and two capacitors can be used as shown in Fig. 18. Here, if there is a 10-to-1 reduction of hum (which is what the ac is called since it produces hum in the output of the device) in each section, the total hum reduction in a two-stage filter network of the type shown in Fig. 18 would be 100. This means that if a 100-volt ac signal is applied to the input of the circuit, there will be a 1-volt ac signal at the output. On the other hand, dc applied to the input would flow through the filter network relatively unhampered.

In a two-stage filter network such as shown in Fig. 18, the first choke, marked L1, is called the input filter choke and the second one, marked

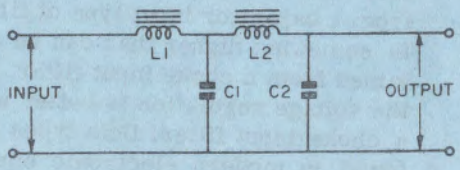


Fig. 18. A two-stage filter network.

L2, is the output filter choke. The choke, L1, is sometimes a special type of choke called a swinging choke. This type of choke is made with a rather small air gap in the core. The core is somewhat smaller than it should be for the amount of current that will flow through the choke so that it saturates rather easily and its inductance varies. The advantage of using this type of choke is that we are able to obtain better voltage regulation at the output of the power supply. By voltage regulation we mean keeping the output voltage more nearly constant as the load or current taken from the power supply vary. The second choke, marked L2, is usually called a "smoothing" choke.

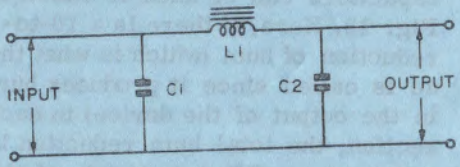


Fig. 19. A capacitor input filter.

Another type of filter network is shown in Fig. 19. This type of filter is often called a brute force filter. Notice that this network uses two capacitors and one choke. This type of network is called a capacitor input filter, whereas the one shown in Fig. 18 is called a choke input filter. In Fig. 19, C1 is called the input capacitor and C2 the output capacitor. The dc output voltage obtained from a capacitor input type of filter is somewhat higher than can be obtained from a choke input filter, but the voltage regulation is better with a choke input filter. Both types are found in modern electronic equipment.

SUMMARY

Chokes are important to the electronics technician, because he will encounter them in most pieces of electronic equipment that he is called upon to service.

Most chokes look like iron-core transformers except that they have only two leads, whereas a transformer has at least three and usually more leads. The cores of chokes are made of laminated sheets of silicon steel. This type of construction is used to keep the eddy current and hysteresis losses low.

Chokes can be saturated if the current passing through them is too high. Therefore, in replacing a defective choke in a piece of electronic equipment, the technician should use a replacement at least as large as the original. Filter chokes are used in conjunction with capacitors to smooth the pulsating dc at the output of a rectifier to pure dc at the output of the filter circuit. Chokes are used for this purpose because they offer a low-resistance path to the flow of dc through them but offer a high reactance to the flow of ac through them. The pulsating dc at the output of the rectifier actually consists of a dc component with an ac component super-imposed on it. The choke lets the dc component go through with little or no effect on it, and in conjunction with the capacitor greatly reduces the ac component.

SELF-TEST QUESTIONS

(ag) How can you tell a filter choke from a power transformer?

(ah) What is the purpose of the fil-

ter choke in a power supply?

(ai) What is the danger of passing too high a current through a filter choke?

(aj) Does a filter choke offer a high resistance or does it offer a low resistance to the flow of dc through it?

(ak) In a two-stage filter network, what are the names given to the two filter chokes?

(al) What is a swinging choke?

Relays

Another magnetic device is the relay. Although relays are used chiefly in transmitters and industrial equipment, they are found in some radio and TV receivers with automatic tuning systems. Relays are used to open and close circuits electrically. They are electric switches. In many ways a relay is similar to a mechanical switch. In order to understand relays, you should understand mechanical switches. So let's look at them first.

SWITCHES

Switches are made with several different contact arrangements. The simplest switch is one that has two positions. In one position, the circuit is open; in the other position the circuit is closed. This is called a single-pole, single-throw switch, abbreviated SPST. Fig. 20 shows an example of this kind of switch. In the position shown at A, the circuit is closed. When the blade is raised as at B, the circuit is open.

The switch illustrated in Fig. 20 is only one kind of SPST switch. They are made with different types of contact arrangements. However, although the mechanisms are different, the electrical principles are the same--in one position of the switch the circuit is open, and in the other position the circuit is closed. An ordinary light switch such as you have in your home is another example of an SPST switch.

Another type of switch, called a single-pole, double-throw switch (SPDT) is arranged so that in one

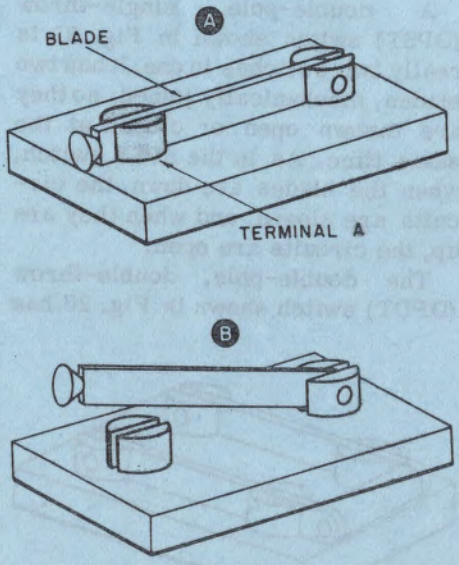


Fig. 20. A single-pole, single-throw switch is shown closed at A, and open at B.

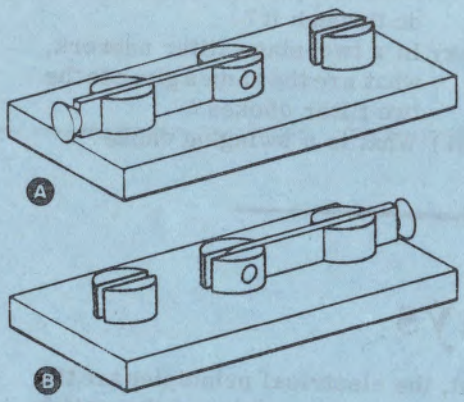


Fig. 21. A single-pole, double-throw switch makes contact in either of the two positions shown at A and B.

position it closes one circuit, and in the other position it closes another circuit. Fig. 21 shows an example of this type of switch.

A double-pole, single-throw (DPST) switch shown in Fig. 22 is really two switches in one. It has two blades, mechanically joined, so they are thrown open or closed at the same time. As in the SPST switch, when the blades are down, the circuits are closed, and when they are up, the circuits are open.

The double-pole, double-throw (DPDT) switch shown in Fig. 23 has

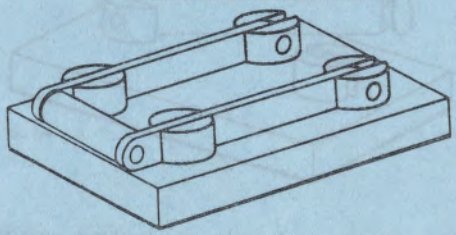


Fig. 22. A double-pole, single-throw switch.

two blades joined mechanically and two closed positions. There are also triple-pole, single-throw (TPST) switches, and triple-pole, double-throw (TPDT) switches.

Relays are also made with all these different types of contacts. Let's see how a relay works.

SIMPLE RELAY CONSTRUCTION

In its simplest form, a relay consists of nothing other than an iron-core coil such as shown in Fig. 24

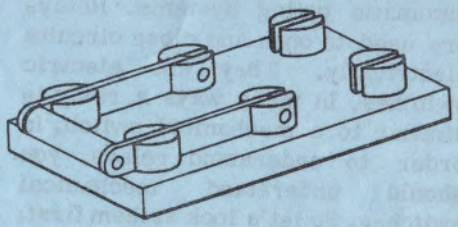


Fig. 23. A double-pole, double-throw switch.

with a bar of magnetic material placed on a pivot near one end of the core. One end of the bar is attached to a spring. The tension of the spring lifts the bar up and away from the core of the magnet. The motion of the top of the bar is usually restricted by some non-magnetic material so that when the relay is not energized, the bar will assume the position shown in Fig. 24A.

When a voltage is applied to the relay coil, current flows through the coil and the magnetic field produced attracts the bar on top of the coil and pulls it down as shown in Fig.

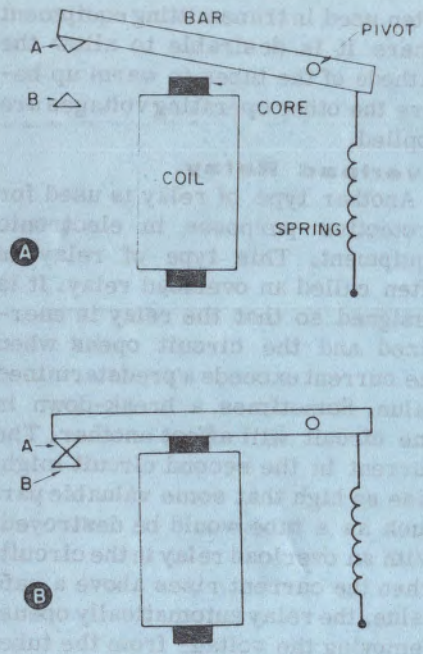


Fig. 24. Basic operation of a relay.

24B so that the contacts A and B are closed. Leads can be connected to terminals A and B so that energizing the relay closes the circuit and current will flow through the circuit.

Some relays operate from dc, but others are made that operate from ac. There is usually not too much difference between small ac and small dc relays, except that the spacing between the bar and the magnet is usually somewhat greater in an ac relay. If the bar comes too close to the magnet in an ac relay, there may be some tendency for the relay to chatter. By chatter, we mean that the bar moves up and down as the ac goes through its cycle and the strength of the magnet varies. If the bar is made of heavy enough material and kept a reasonable distance from the magnet, this problem is usually not encountered in small ac relays.

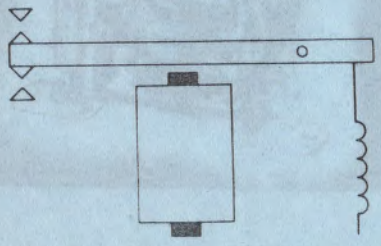


Fig. 25. A single-pole, double-throw relay.

RELAY CONTACTS

The contacts on relays are identified using the same system that is used to identify the contacts on an ordinary switch. The movable arm of a relay or switch may be made to make contact in one position and no contact in the other position, or it may be made to make contact in either of two positions.

If there is only one set of contacts on a relay, we call it a single-pole, single-throw relay. The relay shown in Fig. 24 has this type of contact.

Single-pole, double-throw relays are arranged so that when the coil is energized, it pulls the bar down and the bar makes contact with one terminal and when the coil is not energized, then the bar moves up under the tension of the spring and makes contact with another terminal, as shown in Fig. 25.

Relays are also made with all the other contact arrangements that we

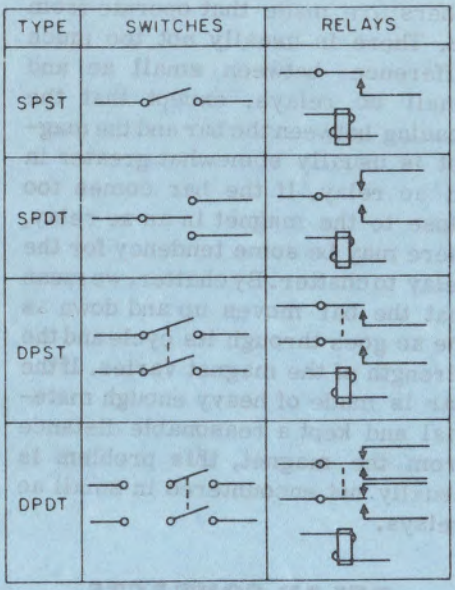


Fig. 26. Schematic symbols for different types of switches and relays.

showed for mechanical switches. Fig. 26 shows the schematic symbols for different types of switches and relays.

SPECIAL PURPOSE RELAYS

There are many special types of relays designed for specific jobs.

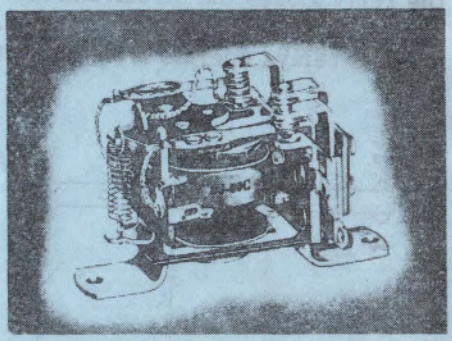
Time-Delay Relay.

One type of relay is a time-delay relay. In this type of relay, the contacts do not close until a predetermined time has elapsed after the power is applied to the relay. After this time has elapsed, the contacts are closed and the circuit is complete. Time-delay relays are usually either SPST or DPST relays. Double-throw time-delay relays are seldom used. Time-delay relays are often used in transmitting equipment where it is desirable to allow the cathode of the tubes to warm up before the other operating voltages are applied.

Overload Relay.

Another type of relay is used for protective purposes in electronic equipment. This type of relay is often called an overload relay. It is designed so that the relay is energized and the circuit opens when the current exceeds a predetermined value. Sometimes a break-down in one circuit will affect another. The current in the second circuit might rise so high that some valuable part such as a tube would be destroyed. With an overload relay in the circuit, when the current rises above a safe value, the relay automatically opens, removing the voltage from the tube, thus saving it from destruction.

As you might expect there are some circuits in which if the current drops below a predetermined value, some damage might result or the equipment might fail to operate



A relay of the type found in electronic equipment. This is a triple-pole, double-throw type.

Fig. 27. A thermal type overload device.

properly. There are relays that are set to open when the current drops below a predetermined value.

Another type of overload device that is widely used in electronics is shown in Fig. 27. This type of overload is not a relay, but instead is made of a metal strip which is made from two dissimilar metals. The current flowing through the strip causes the metals to heat and they expand at different rates. If the metal gets hot enough, the expansion will be great enough to distort the metal so that it springs loose from the contact holding it in place and this opens the circuit. You will run into this type of overload device frequently in electronics. Be sure not to confuse it with an overload relay. It serves the same basic purpose, but it is a thermal overload device rather than a magnetic relay overload device.

SUMMARY

Relays are devices used to close circuits automatically, to protect circuits either by waiting for a predetermined time before closing the circuit or by opening the circuit when an overload occurs. The relay consists of an electromagnet, a bar which can be held in one position by the magnet and returned to the other position by the spring, and one or more sets of contacts.

Relays are found in many different types of electronic equipment. About the only types of defects you are likely to encounter in relays are open coils, and burned or dirty contacts. Sometimes replacement coils are available, sometimes the contacts can be cleaned, but with some types of relays the only suitable remedy for a defect is to replace the entire relay.

SELF-TEST QUESTIONS

(am) What do we mean when we refer to a switch as an SPST switch?

(an) What is meant by SPDT?

(ao) What do the letters DPDT mean?

(ap) What causes the contacts in a relay to close?

(aq) What is a time-delay relay?

(ar) What is an overload relay?

(as) Overload protective devices are frequently found in ELECTRONICS are these overload devices overload relays?

LOOKING AHEAD

The iron-core devices that you studied in this lesson are all devices that will be found frequently in electronic equipment. Of the three, transformers and chokes will be found in more different types of equipment than relays, but there are

many pieces of equipment that use a large number of relays. Defective transformers, chokes, and relay coils can frequently be recognized by a characteristic odor that they give off when they have been overheated. Also, you will generally notice signs of sealing wax and other compounds leaking from an overheated iron-core device. The insulation becomes brittle and can often be crumbled with your fingers. You will not go far in your electronics career before you run into one of these devices that has broken down. Usually it is a simple matter to locate and replace one of these parts that is defective.

In the lessons you have so far studied, you have covered a number of the basic components found in electronic equipment. Now, you are ready to study vacuum tubes, and then see how the components are used with vacuum tubes in amplifiers and other interesting circuits.

ANSWERS TO SELF-TEST QUESTIONS

(a) The gilbert is a unit of magnetomotive force. The gilbert is slightly smaller than the ampere-turn. The gilbert is particularly useful in expressing the magnetomotive force of a permanent magnet.

(b) The maxwell is the unit of magnetic flux. One line of flux is equal to one maxwell.

(c) The flux density is a measure of the number of flux lines passing through a given area. A flux density of one line or one maxwell per square centimeter is known as a gauss.

(d) 100 maxwells or lines. To find the total number of lines you multiply the area in centimeters by the flux density; in this case $10 \times 10 = 100$ lines.

(e) When magnetic saturation occurs, all of the molecules in the core material are aligned with their north poles pointing in one direction and their south poles pointing in the other so that any further increase in magnetomotive force cannot produce any further alignment of the molecules or any increase in flux.

(f) No - in fact it produces a number of undesirable effects and should be avoided.

(g) Magnetic saturation cannot be produced in air regardless of how strong the magnetomotive force is.

(h) A hysteresis loss is a loss due to the inertia of a magnetic circuit. When the core in a choke or transformer is magnetized by passing a current through the coil, the core does not return to a state of zero magnetism when the current is removed. Some magnetism will remain and power must be used to bring the flux density back to zero. This power required to bring the flux density back to zero represents the hysteresis loss.

(i) Eddy current losses are losses due to the fact that a core of the transformer choke acts like a complete turn of a coil and the flux cutting this turn induces a voltage in it which causes a current to flow. This represents a loss which

is known as an eddy current loss.

(j) By selecting a material that has very little magnetic inertia. Materials such as silicon steel have much lower hysteresis loss than soft iron.

(k) Eddy current losses are kept at a minimum by making the core of a transformer or choke coil in the form of sheets of metal rather than a solid piece. The sheets are electrically insulated from each other so that the flow of eddy currents across the entire core material is prevented.

(l) Flux leakage losses are due to the fact that part of the flux escapes from the core and travels through the air surrounding the core. This flux serves no useful purpose since the flux lines in the case of a transformer would not cut the secondary winding of the transformer.

(m) In its simplest form a transformer is two separate coils of wire wound on a common core and placed near each other so that the magnetic lines produced by one coil will cut the other coil.

(n) The two types of losses encountered in a transformer are core losses and copper losses.

(o) The power lost in a transformer is turned into heat. The heat is radiated by the transformer and the chassis on which the transformer is mounted.

(p) Yes. A transformer is one of the most efficient devices you will encounter in electronics. Large power transformers may have efficiencies as high as 98% or better. This means that 98% of the power taken by the primary winding of the transformer is available for useful work at the secondary winding of the transformer.

(q) No. A transformer designed for 50-cycle operation will overheat and burn out if it is operated on a 25-cycle power line.

(r) A step-up transformer is a transformer that has more turns on the secondary winding than on the primary winding. As a result, the voltage available across the output of the secondary winding will be higher than the voltage supplied to the primary winding. The ratio by which the voltage is stepped up is determined by the ratio of the number of turns on each winding of the transformer. In other words, if the secondary winding has twice as many turns as the primary winding, the voltage available across the secondary will be twice the voltage applied to the primary.

(s) 1 amp. A step-down transformer steps the voltage down by the turns ratio; however, it steps the current up by the same turns ratio. Therefore, if the secondary current is 3 amps, the primary current will be only 1 amp.

(t) 1 amps. To find the current we divide the power by the voltage; in this case we have 230 watts divided by 230 volts

equals 1 amps. The efficiency of a transformer is usually so high that we can ignore any losses and if the power consumed by the secondary is 230 watts, we can consider that the primary power will also be 230 watts.

(u) If the turns ratio of a transformer is 2:1, and the transformer is operated on a 240-volt power line, then the secondary voltage must be 120 volts. Since the current drawn by the secondary winding is 4 amps, then the power the secondary winding is supplying is $120 \times 4 = 480$ watts. The primary winding must take this much power from the power line and since the voltage at the power line is 240 volts then the current must be 480 watts divided by 240 volts = 2 amps.

(v) No. Step-up type audio transformers were used in the early days of radio when the gain that could be obtained with a single vacuum tube was comparatively low. By using a step-up type transformer some increase in voltage could be obtained in the transformer and this helped obtain a reasonable voltage amplification in the stage. However, with modern tubes and transistors, adequate gain can be obtained in a stage without resorting to step-up transformers.

(w) Audio transformers are most widely used in electronic equipment as impedance-matching devices. They are used to match the impedance of one stage to the impedance of the following stage, and they are also used to match the impedance of the output stage to the loudspeaker voice coil impedance.

(x) The output stage of a radio or TV receiver must be matched to the speaker voice coil in order to get maximum power transfer from the output stage to the speaker voice coil.

(y) A transformer with a tapped secondary. The center tap on the secondary is either grounded or used to feed bias to the push-pull stages and the signals supplied to the stages are 180° out of phase, so when the current is increasing in one stage of a push-pull amplifier it is decreasing in the other.

(z) The turns ratio must be 10:1. The turns ratio is equal to the square root of

$$\frac{Z1}{Z2}$$

Substituting 1000 ohms for Z1 and 10 ohms for Z2 we find that the turns ratio is

$$\frac{1000}{10} = \sqrt{100}$$

$$\sqrt{100} = 10$$

(aa) An autotransformer is a transformer that consists of a single winding with a tap.

(ab) An autotransformer can be either a step-up transformer or a step-down transformer. If the primary voltage is applied across the entire winding

and the secondary voltage taken off between the tap and one of the primary connections, the transformer will be a step-down transformer. On the other hand, if the primary voltage is applied between the tap and one of the outside connections and the secondary voltage taken off across the entire winding, the output transformer will be a step-up transformer.

(ac) The disadvantage of an autotransformer is that the primary and secondary windings are not completely isolated from each other electrically.

(ad) An rf transformer is a radio frequency transformer used between radio frequency amplifier stages.

(ae) RF transformers have either an air-core or a powdered iron core.

(af) The secondary winding of an i-f transformer, along with the capacitor connected across it, form a series-resonant circuit. This results in a high circulating current and a resonant voltage step-up across the coil and across the capacitor. As a result, the voltage across the coil will be considerably higher than the source voltage. We refer to this increase in voltage as resonant voltage step-up and it explains why the voltage across the secondary winding of an i-f transformer is higher than the voltage across the primary winding.

(ag) A filter choke has only one winding and therefore it has only two leads. Transformers usually have two or three windings and therefore will have more than two leads.

(ah) The filter choke is used in conjunction with filter capacitors to help smooth the pulsating dc from the rectifier output to pure dc.

(ai) The excessive current may over-heat and burn out the wire used to wind the filter choke. In addition, the filter choke may become saturated, even if it doesn't burn out, due to the excessive current flowing through it and its effectiveness as a filter will be reduced.

(aj) A filter choke offers a low resistance to the flow of dc through it. The only opposition the choke offers to dc is the resistance of the choke which is equal to the resistance of the wire used to wind the choke. On the other hand, a filter choke offers a high opposition to the flow of ac through it.

(ak) The two filter chokes are known as the input choke and the output filter choke. The choke connected to the rectifier is the input filter choke, and the other choke is the output filter choke.

(al) A swinging choke is a choke made with a small air gap in the core. The choke is usually somewhat smaller than it would normally be for the amount of current flowing through it and as a result the choke saturates easily. Its inductance varies as the current

flowing through it changes.

(am) SPST means single-pole single-throw. With this type of switch there is only one circuit and in one position the switch is closed and in the other position it is open.

(an) SPDT means single-pole double-throw. With this type of switch one circuit can be completed with the switch in one position and a second circuit can be completed with the switch in the other position.

(ao) DPDT means double-pole double- throw.

(ap) A current flowing through the relay coil produces a magnetic field which attracts a bar which is pivoted above the magnet. The magnet pulls the bar towards the magnet and the the bar closes the relay contacts.

(aq) A time-delay relay is a relay in which the contacts do not close when the relay is at first energized until after a predetermined time has elapsed. This type of relay is frequently found in transmitting equipment - its purpose is to permit the tubes to come up to operating temperature before the high voltages are applied to the tubes.

(ar) An overload relay is a relay used for protective purposes. The relay contacts are normally closed, but if the current flowing through the relay coil exceeds a certain predetermined value the relay contacts will open protecting the circuit in which the relay is used.

(as) No; overloads of this type are thermal overloads and operate when the current flowing through them causes the metal conductor to reach a certain temperature. This causes the metal to spring the contacts open. An overload device of this type is called a thermal overload and is not a relay.

BUDGET SLIDE PROJECTOR PROGRAMMER

Spare components are often all what is needed for this budget SLIDE PROJECTOR PROGRAMMER.

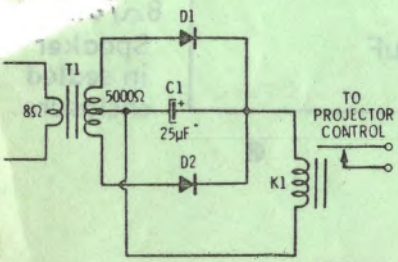
Soundless slide shows are usually dull. However a stereo tape recorder can automate the whole show so that the slides change automatically in sync with prerecorded commentary.

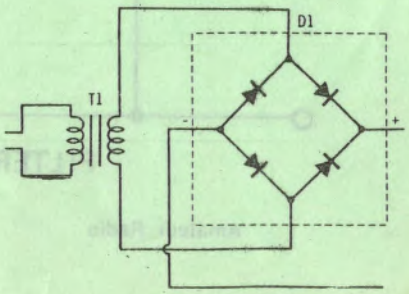
Record your commentary on the left track. At the instant you want slides to change, record a one-second noise or tone burst on the right track. Touching the centre pin of the right channel microphone input with your finger is just as good and does not cost a cent. Connect the slide projector programmer between the right speaker output of the recorder and the remote control cable of the projector. Then make a test run to determine the correct track volume needed to make the noise and/or tone burst activate relay K1. Even a shout can be used as the noise burst.

Start the tape from the beginning. The audience will hear your commentary, music, and sound effects through the left-channel speaker, while the signal on the right channel changes the slides.

PART LIST

C1	Electrolytic capacitor, 25-uf, 50-Vdc
D1,D2	Silicon rectifier, 500-mA, 100-PIV
K1	Relay, 2500-ohm (1000-3000-ohm)
T1	Audio output transformer, 5000-ohm centre tapped primary, 3.2 to 8-ohm secondary to match recorder impedance.





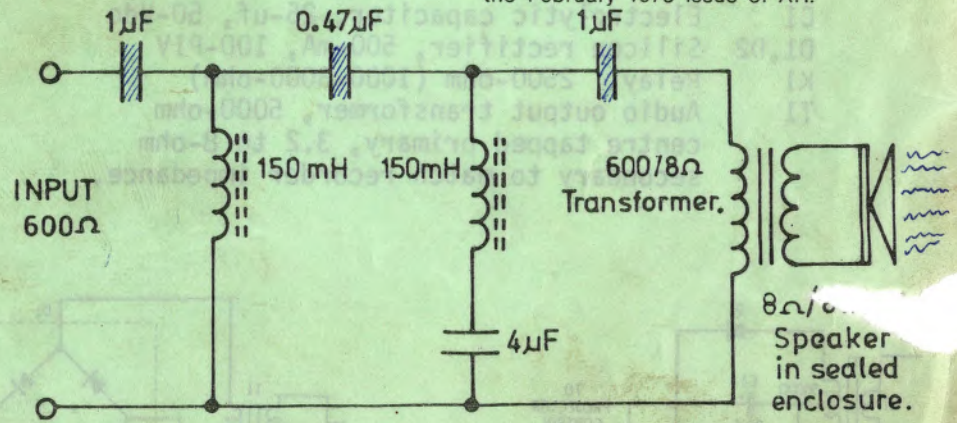
Improvements to the Loudspeaker Filter

In September 1973 an article by VK3BM was published in AR entitled "Improved Loudspeaker Reproduction of SSB". **It described the use of a sealed speaker enclosure and high-pass filter to improve intelligibility under noisy band conditions by attenuation of the lower audio frequencies. VK5NN suggested (in a letter to VK3BM) that the filter could be made much more effective by modifications which are the subject of this article.**

The original filter was designed for use with an 8 ohm speaker. At such a low impedance level the capacitors are relatively large, electrolytics being unavoidable, and the inductors tend to have a low effective Q. Consequently the filter efficiency is low, and the attenuation increases only slowly as frequency drops below cut-off. If a higher impedance is used, requiring larger inductors and smaller capacitors, the filter efficiency can be improved. Also, with more practical sizes of components, it becomes simpler to add another stage to the filter and obtain a much sharper cut-off. Incidentally, there was an error in the original article in that the centre capacitor should have been only 30 microfarads rather than 60, but this does not produce any great change in the performance.

COMPONENTS

It is suggested that the filter capacitors should be the polyester type, of 100 or 160 volt rating. The 4 microfarad value may need to be made up of two 2.0 or 2.2 microfarad units in parallel, or perhaps an old-style block paper capacitor may be available from the junk-box. None of the values is especially critical. For the inductors the use of ferrite pot-cores is recommended (type FX2242 or similar). The manufacturer's data on such cores usually gives a figure for the number of turns to give 1 millihenry inductance. Since inductance is proportional to the square of the number of turns, about 12½ times the 1 mH turn figure will give the desired 150 mH. More information may be found if desired in the article "Building High-Q Inductors with Ferrites" by VK3ZRQ in the February 1973 issue of AR.



FILTER CIRCUIT.

Amateur Radio

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